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ASSESSMENT OF THE PERFORMANCE OF AN ACTIVE ATCRBS MODE FOR BEACON COLLISION AVOIDANCE.

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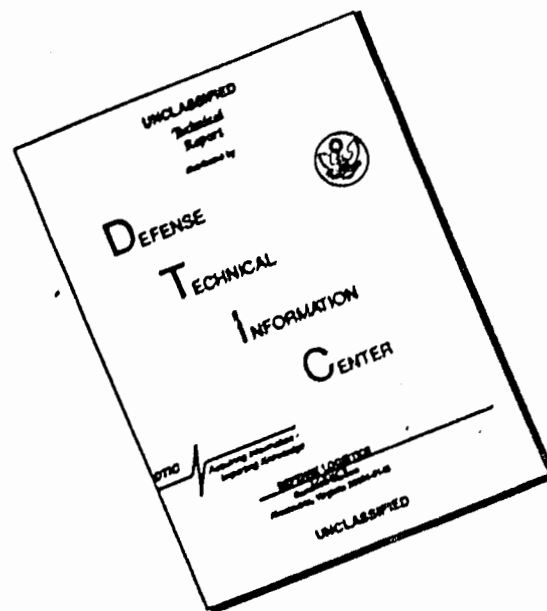
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16. Abstract The active ATCRBS Mode of BCAS was tested in a NAFEC airborne test bed. After conducting many flights for purposes of the system shakedown, design refinement, and the setting of parameters, a series of detailed data collection flights was run. The report presents first, the results of approximately 100 one-on-one aircraft encounters in which the ability of BCAS to give a proper maneuver command was examined; second, the results of one and one-quarter hours of data on targets-of-opportunity in the environment of the Washington, D.C. TCA; and third, an examination of flights with a controlled target aircraft in the airspace near NAFEC to explore the effects of antenna coverage. A comparison is made between the results obtained in Washington, those from NAFEC flights, and those from simulated scenarios fed into the operating processor. ↑			
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
m ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in = 2.54 in exactly. For other exact conversions and more data and tables, see NBS Mon. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C-13-110-286.

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	ac
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	st
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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The close, cooperative working relationship established between Messrs. M. Cohen and C. Richardson of NAFEC and Dr. P. Ebert and Mr. J. Hill of MITRE METREK played a major role in the successful construction, integration, and testing of the equipment. Dr. Ebert also guided the design, troubleshooting, and analysis of the system. Mr. L. Moses devoted much time and effort in arriving at a meaningful data reduction package, and was able to overcome many troublesome conditions.

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SUMMARY

This report describes the results of numerous measurements made on the active ATCRBS mode of BCAS as conducted on the NAFEC flying test bed. Many one-on-one encounters were flown with an ATCRBS-equipped aircraft to determine the overall capability to provide collision avoidance maneuvers. For the approximately 100 encounters flown (most at NAFEC, 16 at Washington, D.C.) correct and timely indication was provided.

A more detailed examination was also conducted into the quality of the tracks in the Washington, D.C. area and at NAFEC. It was found that aircraft antenna shielding, encountered because of the bottom-mounted transponder antennas, was the major factor affecting the overall tracking performance. Auxiliary tests made to localize this fact pointed to the conclusion that synchronous garble and tracker parameters caused relatively little degradation in the Washington airspace as compared to antenna shielding. The importance of the antenna shielding phenomenon is evidenced by the fact that when the other aircraft is above the BCAS aircraft, tracks are essentially continuous; whereas, when the other aircraft is below, the tracks exist for 70 to 75 percent of the time.

Another characteristic of the active ATCRBS mode which was analyzed is the inadvertent possibility of producing false, or phantom, tracks. This is a function of traffic density and aircraft relative geometry. In the Washington area phantom tracks within 5 nmi of the BCAS aircraft were found to occur about one-third of the time. The characteristics of these tracks, however, are that they are of very short duration. This indicates that significant improvements would be available by revising the criteria for track establishment. Further, during the exercise in the Washington area, commands were observed only for the

intentional encounters--no false commands were issued. While it might thus appear that the resulting impact would be small, the prevalence of possible phantom threats was about 20 percent of the possible real threats, so this is a factor that must not be overlooked.

Overall, the tests indicate that a substantial degree of protection could be made available from the active ATCRBS portion of BCAS, and they point to the way for making some further improvements.

TABLE OF CONTENTS

	<u>Page</u>
1. INTRODUCTION	1-1
2. EQUIPMENT DESCRIPTION	2-1
3. EARLY TESTING AND SHAKEDOWN	3-1
3.1 Several of the Problems Discovered and Solved During the First Year of Flight Tests	3-2
4. ENCOUNTER TESTING	4-1
5. PERFORMANCE IN WASHINGTON, D.C. AREA	5-1
5.1 Separation of Real Tracks and Phantom Tracks	5-2
5.2 Overall Performance Statistics	5-3
6. ANALYSIS OF HIGH DENSITY RESULTS FOR BCAS ASSOCIATED AIRCRAFT TRACKS	6-1
6.1 Synchronous Garble	6-1
6.1.1 Association as a Function of Overlapping Replies	6-1
6.1.2 Comparison with Whisper-Shout Technique	6-2
6.1.3 Simulation of Garble	6-4
6.2 Communication Link	6-8
6.2.1 Dependence of Association on Altitude	6-8
6.2.2 BCAS Track Correlation	6-10
6.2.3 One-on-One Tests at NAFEC	6-11
6.2.4 Ground Reflections	6-15
6.2.5 Power Budget and Interrogator Protocol	6-19
6.3 Tracker Logic	6-24
6.4 Summary of Analysis of Association Performance	6-25
7. ANALYSIS OF HIGH DENSITY RESULTS FOR PHANTOM TRACKS	7-1
APPENDIX A: DATA COLLECTED IN WASHINGTON, D.C. AREA	A-1
APPENDIX B: DATA COLLECTED IN NAFEC TESTS TO DETERMINE COVERAGE	B-1
APPENDIX C: POWER BUDGET	C-1
APPENDIX D: DABS INTEGRATION	D-1
APPENDIX E: REFERENCES	E-1

LIST OF ILLUSTRATIONS

	<u>Page</u>
TABLE 5-1: FRACTION OF BCAS ASSOCIATED AIRCRAFT TRACKS	5-4
TABLE 5-2: PHANTOM TRACK RATE	5-4
TABLE 6-1: TRACKING PERFORMANCE AT NAFEC	6-16
TABLE A-1: PEAK TRAFFIC CONDITIONS	A-7
TABLE C-1: POWER BUDGET	C-2
FIGURE 2-1: TEST BED BLOCK DIAGRAM	2-2
FIGURE 2-2: INTERROGATION SEQUENCE	2-4
FIGURE 2-3: DATA PROCESSING FLOW	2-5
FIGURE 6-1: RATIO OF SAMPLES OF ARTS TRACKS ASSOCIATED WITH BCAS TRACKS	6-3
FIGURE 6-2: SIMULATED TRAFFIC SCENARIO	6-5
FIGURE 6-3: SIMULATION OF BCAS ABILITY TO HOLD TRACK THROUGH GARBLE	6-7
FIGURE 6-4: ASSOCIATION DATA FOR BASIC MODE	6-9
FIGURE 6-5: CORRELATION CHARACTERISTICS OF ASSOCIATED BCAS TRACKS (BASIC SYSTEM)	6-12
FIGURE 6-6: SUMMARY OF ONE-ON-ONE TRACKS FOR FLIGHTS AT NAFEC	6-14
FIGURE 6-7: OUTBOUND HEAD-ON ENCOUNTER (+1000 FT.)	6-18
FIGURE 6-8: GENERIC ANTENNA COVERAGE PATTERNS	6-21
FIGURE 6-9: MEASURED TRANSPONDER CHARACTERISTICS	6-23
FIGURE 7-1: PHANTOMS GENERATED BY AIRCRAFT ON GROUND	7-2
FIGURE A-1: TOTAL AIRCRAFT TRACK MATRIX (R VS Z)	A-13
FIGURE A-2: TOTAL AIRCRAFT TRACK MATRIX (R VS \dot{R})	A-14
FIGURE A-3: TOTAL BCAS ASSOCIATED AIRCRAFT TRACK MATRIX (R VS Z)	A-15
FIGURE A-4: TOTAL BCAS ASSOCIATED AIRCRAFT TRACK MATRIX (R VS \dot{R})	A-16
FIGURE A-5: RATIO OF BCAS ASSOCIATED AIRCRAFT TRACKS TO TOTAL AIRCRAFT TRACKS (R VS Z)	A-17

LIST OF ILLUSTRATIONS

(Continued)

	<u>Page</u>
FIGURE A-6: RATIO OF BCAS ASSOCIATED AIRCRAFT TRACKS TO TOTAL AIRCRAFT TRACKS (R VS \dot{R})	A-18
FIGURE A-7: AIRCRAFT ASSOCIATION, FOR EACH MILE, FOR ALL ALTITUDES	A-19
FIGURE A-8: AIRCRAFT ASSOCIATION, EACH MILE, FOR VARIOUS ALTITUDE ZONES	A-20
FIGURE A-9: BCAS PERFORMANCE FOR VARIOUS ALTITUDE AND RANGE ZONES	A-22
FIGURE A-10: CUMULATIVE PERCENT OF AIRCRAFT ASSOCIATION	A-23
FIGURE A-11: PROBABILITY OF PHANTOM OCCURRENCES (R VS Z)	A-24
FIGURE A-12: PROBABILITY OF PHANTOM OCCURRENCES (R VS \dot{R})	A-25
FIGURE A-13: ARTS ASSOCIATION VS. OVERLAPS (BASIC)	A-26
FIGURE A-14: ARTS ASSOCIATION VS. OVERLAPS (WHISPER-SHOUT)	A-27
FIGURE A-15: ARTS ASSOCIATION VS. AIRCRAFT DENSITY (BASIC)	A-28
FIGURE A-16: ARTS ASSOCIATION VS. AIRCRAFT DENSITY (WHISPER-SHOUT)	A-29
FIGURE A-17: BCAS TRACK CORRELATION VS. OVERLAPS (BASIC)	A-30
FIGURE A-18: BCAS TRACK CORRELATION VS. OVERLAPS (WHISPER-SHOUT)	A-31
FIGURE A-19: BCAS TRACK CORRELATION VS. DENSITY (BASIC)	A-32
FIGURE A-20: BCAS TRACK CORRELATION VS. DENSITY (WHISPER-SHOUT)	A-33
FIGURE A-21: BCAS CONSECUTIVE COAST STATUS FOR ASSOCIATED TRACKS	A-34
FIGURE A-22: ASSOCIATION PERFORMANCE AS A FUNCTION OF RANGE AND OVERLAPS	A-35
FIGURE A-23: ASSOCIATION PERFORMANCE AS A FUNCTION OF DENSITY AND OVERLAPS	A-36
FIGURE B-1: INBOUND HEAD-ON ENCOUNTER (-1000 FT.)	B-2
FIGURE B-2: OUTBOUND HEAD-ON ENCOUNTER (-1000 FT.)	B-3
FIGURE B-3: INBOUND HEAD-ON ENCOUNTER (-2000 FT.)	B-4
FIGURE B-4: OUTBOUND HEAD-ON ENCOUNTER (-2000 FT.)	B-5

LIST OF ILLUSTRATIONS

(Continued)

	<u>Page</u>
FIGURE B-5: INBOUND HEAD-ON ENCOUNTER (-3000 FT.)	B-6
FIGURE B-6: OUTBOUND HEAD-ON ENCOUNTER (-3000 FT.)	B-7
FIGURE B-7: INBOUND HEAD-ON ENCOUNTER (-4000 FT.)	B-8
FIGURE B-8: OUTBOUND HEAD-ON ENCOUNTER (-4000 FT.)	B-9
FIGURE B-9: INBOUND CROSSING ENCOUNTER (-4000 FT.)	B-10
FIGURE B-10: OUTBOUND CROSSING ENCOUNTER (-4000 FT.)	B-11
FIGURE B-11: INBOUND CROSSING ENCOUNTER (-3000 FT.)	B-12
FIGURE B-12: OUTBOUND CROSSING ENCOUNTER (-3000 FT.)	B-13
FIGURE B-13: INBOUND CROSSING ENCOUNTER (-2000 FT.)	B-14
FIGURE B-14: OUTBOUND CROSSING ENCOUNTER (-2000 FT.)	B-15
FIGURE B-15: INBOUND CROSSING ENCOUNTER (-1000 FT.)	B-16
FIGURE B-16: OUTBOUND CROSSING ENCOUNTER (-1000 FT.)	B-17
FIGURE B-17: INBOUND HEAD-ON ENCOUNTER (+1000 FT.)	B-18
FIGURE B-18: OUTBOUND HEAD-ON ENCOUNTER (+1000 FT.)	B-19
FIGURE B-19: INBOUND HEAD-ON ENCOUNTER (+2000 FT.)	B-20
FIGURE B-20: OUTBOUND HEAD-ON ENCOUNTER (+2000 FT.)	B-21
FIGURE B-21: INBOUND HEAD-ON ENCOUNTER (+3000 FT.)	B-22
FIGURE B-22: OUTBOUND HEAD-ON ENCOUNTER (+3000 FT.)	B-23
FIGURE B-23: INBOUND HEAD-ON ENCOUNTER (+4000 FT.)	B-24
FIGURE B-24: OUTBOUND HEAD-ON ENCOUNTER (+4000 FT.)	B-25
FIGURE B-25: INBOUND CROSSING ENCOUNTER (+4000 FT.)	B-26
FIGURE B-26: OUTBOUND CROSSING ENCOUNTER (+4000 FT.)	B-27
FIGURE B-27: INBOUND CROSSING ENCOUNTER (+3000 FT.)	B-28
FIGURE B-28: OUTBOUND CROSSING ENCOUNTER (+3000 FT.)	B-29
FIGURE B-29: INBOUND CROSSING ENCOUNTER (+2000 FT.)	B-30
FIGURE B-30: OUTBOUND CROSSING ENCOUNTER (+2000 FT.)	B-31
FIGURE B-31: INBOUND CROSSING ENCOUNTER (+1000 FT.)	B-32
FIGURE B-32: OUTBOUND CROSSING ENCOUNTER (+1000 FT.)	B-33
FIGURE D-1: SOFTWARE CONFIGURATION OF UPGRADED ACTIVE MODE TEST BED	D-3

1. INTRODUCTION

The FAA concept for a Beacon-based Collision Avoidance system includes several features--active mode, passive mode, DABS mode, ATCRBS mode. This report presents some results of a test and evaluation (T&E) program conducted on feasibility equipment for the active ATCRBS mode of BCAS. The particular technique investigated sends out, omnidirectionally, a mode C (altitude) interrogation on a one-second cycle, it receives and processes all returns, delivers target information (R, \dot{R} , Z, \dot{Z}) to a threat evaluator, and provides resolution maneuvers on an indicator.

The threat evaluation and resolution logic was not the primary subject of this T&E program; although modification of a standard logic (Reference 1; ANTC-117) was used to demonstrate the display. Instead, the object was to shed light on the ability of the equipment to detect, sort out, and track the many overlapping replies that arrive in response to a single omnidirectional interrogation. The technical approach used is described in Reference 2.

The attraction of BCAS with regard to validation testing is that many aircraft are equipped with transponders and altitude encoders and therefore BCAS can be tested in a truly live environment. Several approaches were used to test the technique. One-on-one encounters were flown, usually near Atlantic City, NJ in which both the ability of the system to sense and resolve potential conflicts was observed and the accuracy of the system could be compared against an optical theodolite system on the ground. One-on-one flights at various altitude separations were flown to evaluate RF coverage conditions. Flights in the immediate vicinity of Washington, D.C. were conducted in which targets-of-opportunity were observed. Digital

simulations of specific flight scenarios were run. All these tests ranged from having ideal control of the situation using the simulation, but being the least realistic, to having very poor control for the targets-of-opportunity, but being the ultimate in realism.

The most extensive tests were those in which BCAS tracked the targets-of-opportunity, which were then compared with tracks obtained from the ARTS III extractor data for the same period. With an ARTS scan about every 4.7 seconds a considerable amount of data is gathered every flight (i.e., in one hour there are over 750 ARTS scans, 3600 BCAS interrogations, and about 300 aircraft which come into BCAS view). The data reduction package which was developed for this analysis represents a substantial amount of experience, including earlier ARTS efforts and many BCAS-peculiar considerations encountered in the present effort.

All flight tests were conducted by the FAA's System and Equipment Engineering Branch at NAFEC. In addition, the procurement of feasibility equipment, obtaining the necessary modifications, and much of the system integration effort was carried on by NAFEC. A NAFEC report describing details of the feasibility equipment and some results of early series of flight tests is noted as Reference 3.

The equipment used in this evaluation was assembled from a combination of modified off-the-shelf items and a few special purpose devices. The features tested were the Basic ATCRBS interrogation features and a capability called Whisper-shout, which is intended to augment the capacity of the Basic system.

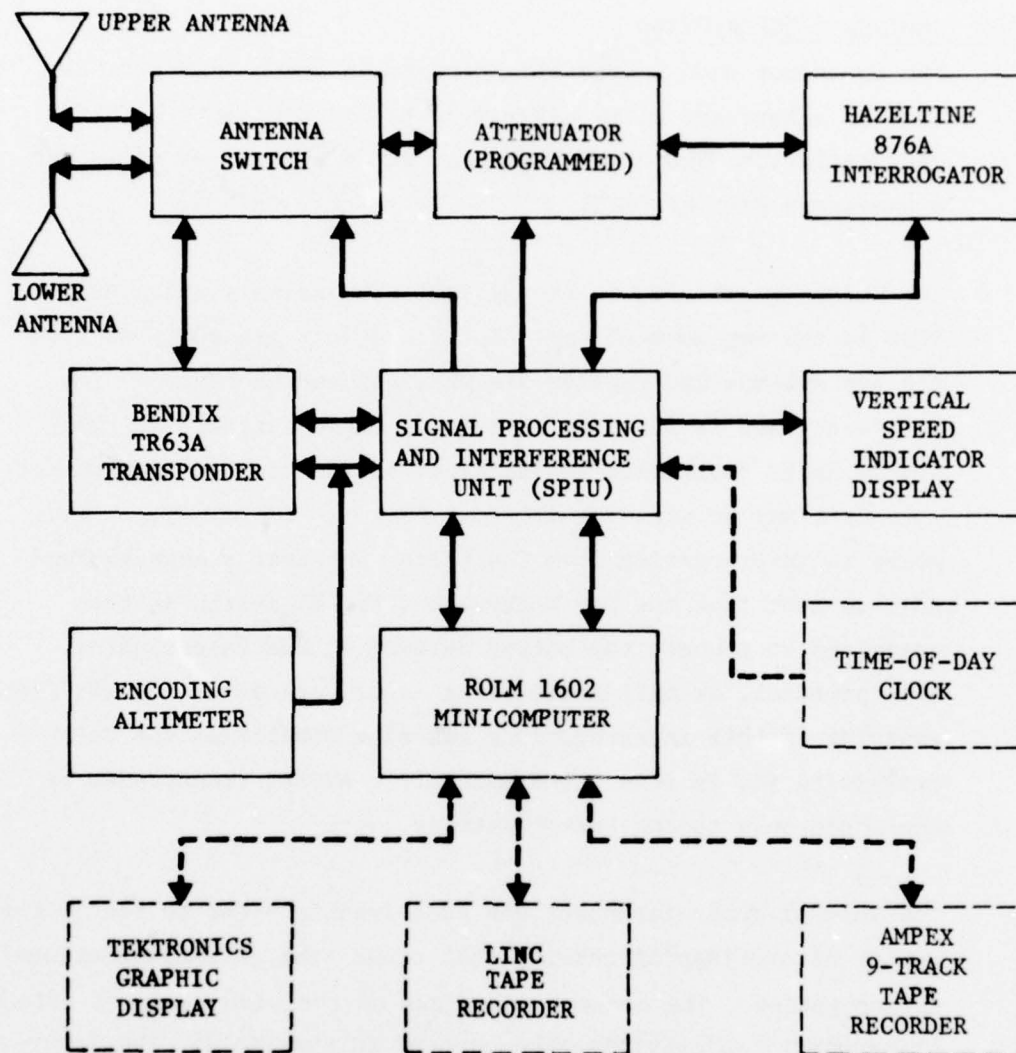
Details of the equipment, interrogation protocol, etc. are given in the next section. A discussion of early tests and shakedown is then presented, to give an idea of the evolution of this equipment from its start to the evaluation tests in the spring of 1977. The measured results are then shown, both for the ability to generate collision avoidance commands in encounters and for the detailed tracking of targets. This is followed by an analysis of the results and conclusions as to their implications. Appendix A and B contain printouts and plots of this data.

2. EQUIPMENT DESCRIPTION

The equipment used in the flight tests is shown in Figure 2-1. This is a hardware block diagram, with the equipment used for data collection and graphic display shown dotted, as it is not a necessary part of BCAS.

Two antennas are used in the system. The primary antenna for BCAS is the top-mounted one. Interrogations are sent out from the top antenna and replies are obtained and processed. The bottom antenna is intended to acquire those aircraft at relatively large depression angles whose bottom-mounted transponder antenna's may be severely shielded from our top antenna. Just prior to interrogating from the bottom antenna, a suppression-pair is sent from the top antenna and the RF switch is then energized to connect the bottom antenna to the interrogator. This protocol, as will be discussed later, prevents aircraft from replying to both interrogations and also simplifies the data processing job in BCAS. The aircraft's ATCRBS transponder is connected only to the bottom antenna.

The Whisper-shout technique was conceived in order to reduce the number of overlapping replies that occur from an omnidirectional interrogation. The concept makes use of the wide range of effective transponder sensitivities encountered in the field. The interrogation is first sent out at a very low power level (whisper) so that only the more sensitive transponders at a given range will reply. After these replies are detected (about 10 ms later) a $P_1 P_2$ suppression pair is sent at nearly the same power level, followed within a few microseconds by another interrogation at higher power (shout). This has the effect of silencing those aircraft which have already replied to the whisper, and evokes replies from the less sensitive transponders for further processing.

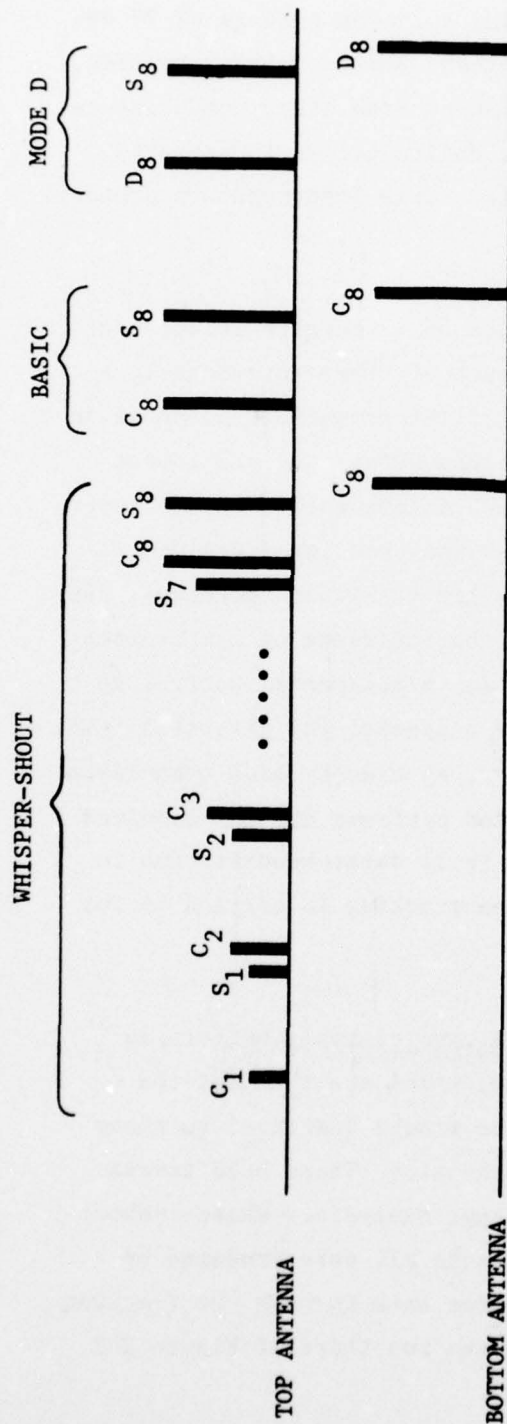


**FIGURE 2-1
TEST BED BLOCK DIAGRAM**

The test bed used eight power levels, spanning a range of 27 dB. The result is that, for each level there are much fewer replies, and therefore fewer overlaps, (estimated from other measurements to be about 25 percent). After the entire cycle, the results are then processed in the track file. This interrogation protocol is used on the top antenna only.

The test system goes through a series of 12 interrogations each second and records the replies to each of these interrogations on the 9-track tape. The sequence of interrogations is shown in Figure 2-2, starting with a top antenna whisper at the lowest power level, and ending with a Mode-D interrogation on the lower antenna. This set of interrogations was used for experimental data collection--it elicits replies for the Basic technique, the Whisper-shout technique (to reduce the incidence of synchronous garble), and in response to Mode D (an experimental control to provide garble-free performance for a special FAA aircraft). The entire cycle only takes about 120 ms, so side-by-side comparison can readily be made. The test system performs all the required interrogations and records all the reply data; however, due to time and memory constraints airborne tracking is carried on for only one system--usually Basic.

Once back on the ground the 9-track tape of reply buffers is converted to a number of Linc tapes, which are then entered into the tracking program to produce tracks identical to those which would have been produced in the air. These BCAS tracks are recorded on 9-track tape for later analysis. Whisper-shout tracks, Basic tracks, and Mode D tracks all were produced by passing the corresponding reply-buffer data through the tracking program. This routine is shown as the top third of Figure 2-3.



C_i = Mode C Interrogation at power level i

D_i = Mode D Interrogation at power level i

S_i = Suppression-pair at power level i

sub_i = Transmitted power levels 1-8 (8 = full power)

FIGURE 2-2
INTERROGATION SEQUENCE

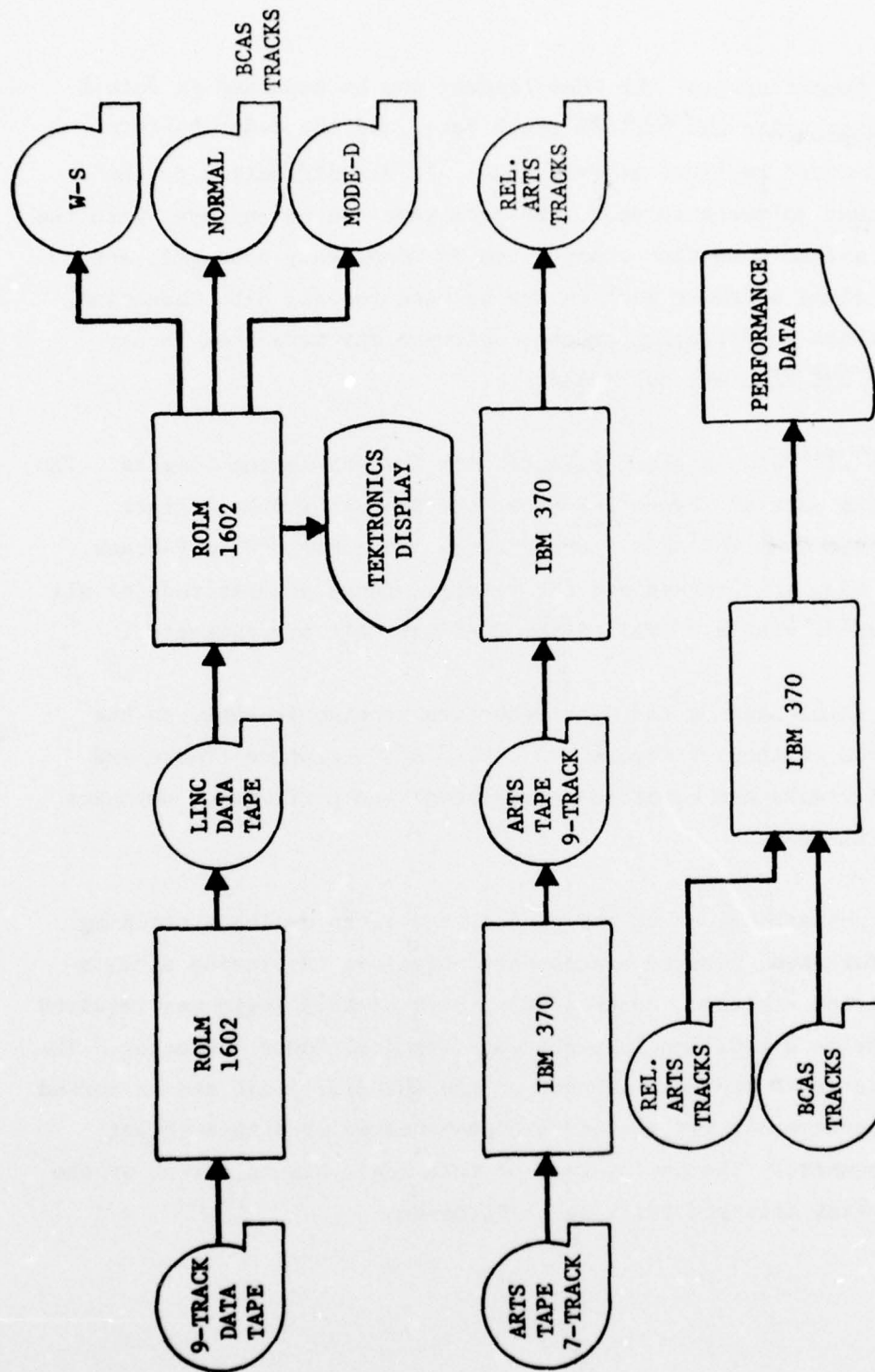


FIGURE 2-3
DATA PROCESSING FLOW

The functioning of the BCAS tracker can be examined in detail by displaying the various track data, and the radar buffers of decoded replies, every second. If a modification to the tracker software is made, the data tape can be replayed with the new software so that changes can be completely debugged, and one final software package can be used for all data reduction, even though different tracker software may have been in use when the data was collected.

ARTS III data is also collected for the Washington flights. The middle part of Figure 2-3 shows the process whereby target reports from the ARTS 7-track tapes are converted to 9-track, and then are tracked and the relative range and altitude of all aircraft within 20 nmi of the BCAS aircraft are extracted.

The final step of the data reduction process is shown on the bottom portion of Figure 2-3. Here ARTS relative tracks and BCAS tracks are compared (associated) and performance measures are extracted.

The primary object of the test system is to evaluate tracking performance, however a secondary object is to provide a demonstration vehicle. Consequently, an avoidance logic was required to drive a modified Instantaneous Vertical Speed Indicator. The logic was a modified version of the ANTC-117 logic and it worked satisfactorily for all of the non-maneuvering single-threat encounters. The performance of this logic has no affect on the tracking data and tracking performance.

3. EARLY TESTING AND SHAKEDOWN

The BCAS flight test system shown in Figure 2-1 is the result of two years of flight experience--approximately 60 flights. The original system, assembled in October of 1975 did not have the programmable attenuator, the 9-track tape recorder or the graphic display. At that time, only full power interrogations were made on the upper and lower antennas, and data was recorded directly on the Linc tape (the same unit that was used to load programs). The tracks could be displayed graphically, but only after the flight, when the data tape was played back in the laboratory.

The first year of flight testing was spent improving the video and detection circuits, tuning the tracker, and developing a data reduction package that would compare the BCAS tracks to ARTS tracks. These first tests provided data on the accuracy of the tracked range, range rate, altitude, and altitude rate, and on the extent of shielding caused by the use of a single transponder antenna on the bottom of the threat aircraft. In the first few flights it was discovered that the fruit rate was higher than expected, but not high enough to seriously affect the tracker.

Because synchronous garble was recognized as a major problem to be faced by the active ATCRBS mode of BCAS in high traffic environments the test bed was modified to interrogate with a multilevel (Whisper-shout) signal.* The software was modified to do the sequence of 12 interrogations described in Section 2, and a higher capacity tape recorder was added to facilitate recording this additional data. The graphic display was also added to the test bed so that the overall functioning could be

* Modifications were also made to drive a 4-beam antenna, but this capability was never exercised.

monitored while under way rather than waiting to get the data tape back to the laboratory.

This system was flown on many flights, but very little synchronous garble was observed due to the low traffic density in the Atlantic City area. Therefore, a request was made, and permission was granted to fly a few tests directly over National Airport, just above the most dense traffic in the Washington area. On two days, about one and one-quarter hours of data was obtained, and this is the major data that is presented in this report.

3.1 Several of the Problems Discovered and Solved During the First Year of Flight Tests

On the first flight into Washington the receiver was overwhelmed by the number of replies. These were determined to be fruit caused by setting the receiver sensitivity too high (about -87 dBm). This was first reduced to -81 dBm, and later to -76 dBm for the set of flights described in this report.

It was observed that occasionally a radar buffer would be completely full, and adjacent buffers (one second apart) would only be lightly populated. In addition, many of the altitude reply codes in the full buffer would be 7777 (all one's), as if some burst of RF had hit the receiver. These were concluded to be replies to a distant radar of the aircraft that were between that distant radar and the test aircraft. All such replies would arrive within a narrow time interval, and these bursts were observed to reoccur about every 10 or 11 seconds. An immediate reinterrogation would have recovered the lost data but was not implemented because the amount of lost data was insignificant.

It was next observed that many altitude bits, or whole replies were missing in garble situations. An examination of the hardware showed that both the interrogator receiver, and the video processor in the SPIU (taken directly from an ARTS II system) were built to restore the video pulse shape and width in the absence of garble. However, when garble was present and pulses were overlapped, the receiver and processor deleted portions of the received pulses. Since the BCAS detector and tracker was designed to work with additions (garble and fruit) rather than deletions, the video processor had to be modified.

It was also discovered that some of the altitude bits were being lost because the jitter in the data sampler sometimes carried it off the trailing edge of the pulse. This was corrected by taking the "OR" of two adjacent video samples.

Throughout the flight tests it was known that IF ringing caused strong signals to have much wider framing and altitude pulses. This tends to add more 1's than necessary, for garbled replies, but this was not considered to be a serious deficiency since the purpose of the Whisper-shout interrogations and the tracker is to remove these extra 1's. The DABS modification to the test bed contains a new digital video processor which completely eliminates this pulse widening, however all the data presented in this report was collected before the new digital video processor was installed.

A fair amount of testing went into the Whisper-shout technique, both before and after the modifications were made to the test bed. Before the modifications were made, a two-level Whisper-shout was tested using the antenna switch and a circulator. These tests

showed that the population can be broken up into groups without too many overlapping or missing reports. After the Whisper-shout enhancement was installed, the interrogation and suppression levels had to be adjusted to yield eight approximately equal groups of replies.

4. ENCOUNTER TESTING

In most of the test flights flown with two aircraft, the procedure was to fly the test aircraft on a collision course but with an offset of 400 feet in altitude, after initial altitude calibration. This offset was small enough to make the BCAS system alert and display an evasive command, but large enough that the aircraft were in no danger of accidental collision.

The primary object of the flight tests was to obtain data on tracker performance, but a log was kept of commands displayed for each encounter.* There were slightly over 100 encounters. Several times, early in the flight test, the wrong indication was given (dive, when the threat was below) this was found to be a software error, and when the error was corrected and the recorded data replayed, the indication was correct. All warnings were given at least 30 seconds before crossover, and all were in the correct direction.

Although most of the encounters were in the vicinity of NAFEC, where there is relatively little traffic, the crossovers occurred directly over the NAFEC VORTAC, and the numerous fixed transponders on buildings and taxiing aircraft contributed to synchronous garble. However, 16 encounters were flown in the heavily trafficked Washington area with the same results noted above.

Throughout the many flights when no intentional encounters were flown, some climb or dive indications were observed. Most of these were visually correlated with passing aircraft.

* The nature of the test was to record whenever a command was displayed, but not to maneuver the aircraft.

One apparent problem with the logic was observed on a flight at NAFEC on June 1977. Mistakenly, the target aircraft crossed the 30 second Tau threshold without any significant altitude difference. In this case the logic choses a climb or dive depending on the momentary altitude separation, and is as likely to be a dive as a climb. In the observed case the BCAS logic commanded a dive because the threat was slightly above at $\tau = 30$ seconds. As the aircraft got closer the target aircraft finally dropped to a lower altitude, but the BCAS logic was programmed to hold the original command, based on the assumption that the pilot was already starting a dive, and a change in command would be disturbing, if not dangerous. The BCAS pilot, following the test procedure, did not dive and the target aircraft passed under him, giving the impression that the logic was operating incorrectly; it was in fact operating as intended. The result of this situation was to reconsider the logic with regard to possibly changing the original command presented to the pilot.

5. PERFORMANCE IN WASHINGTON, D.C. AREA

The most stringent tests of feasibility were encountered when the equipment was flown just over the TCA at Washington National Airport. The intention was to insert a single aircraft carrying the ATCRBS active-mode system into the traffic densities encountered in a major terminal. A second aircraft, carrying only a calibrated ATCRBS transponder was also introduced into the flight pattern.

The BCAS aircraft flew back and forth over the TCA at 7500 feet; the "target aircraft" flew back and forth at right angles to the BCAS flight path. These high density tests occurred during the early afternoon of Friday, 6 May 1977, and Thursday, 12 May 1977. Approximately one hour and fifteen minutes of data was collected. The average load, as determined from the ARTS III data, was 7 mode-C-responding aircraft within 10 miles of our BCAS aircraft, peaking to 15 aircraft at times.

As noted earlier, the main analysis compares BCAS tracks with ARTS tracks. To obtain the ARTS tracks, copies of extractor data tapes were first made. Then a tracker similar to that resident within ARTS was constructed, based on earlier MITRE METREK work. This tracker was extended to provide tracks on all mode-C-reporting aircraft, thereby providing tracks on VFR aircraft as well as on aircraft not otherwise under control of the ARTS facility.

When ARTS tracks are obtained on other aircraft, they then must be vectorially subtracted from the ARTS track of the BCAS aircraft to obtain an ARTS relative track. This will then provide altitude and relative range, which may be compared (associated) with BCAS tracks. A BCAS track and an ARTS relative track are said to be associated if their altitudes are within 300 feet and their

ranges are within one mile of each other. Further specifics are given in Appendix A.

Two performance measures are assessed, namely: the ability of BCAS to produce a track when ARTS has shown that an aircraft is present; and the generation of false BCAS tracks, or phantoms. Phantom tracks are generated most often when several overlapping replies remain in their same relative position for an extended period of time, since relative motion between replies is relied on to eliminate phantoms. The situation has been most often observed near large airports, where transponders from several aircraft may be energized while they are on the taxiway. More will be said about this later.

5.1 Separation of Real Tracks and Phantom Tracks

Every ARTS scan (an interval of about 4.7 seconds) a tabulation is made of all the relative ARTS tracks and of all the BCAS tracks, and an attempt is made to associate them. So on every scan there are three classes of tracks--ARTS tracks that associate with BCAS tracks, ARTS tracks that do not associate with BCAS tracks, and BCAS tracks that do not associate with ARTS tracks.*

The discernment of a phantom track is a particularly difficult task, since it cannot be established whether the observed unassociated BCAS track is really a phantom or whether it is due to a real aircraft not being tracked by ARTS at that time. For

* Recall that these are tracks, not reports. A track implies a measure of confidence has been established. The track may be updated by a just-received report, or it may be coasted to a predicted position if the report is missing. The rules for track establishment and track drop are complex, and may be found in Appendix A and in Reference 5.

the purposes of this analysis a phantom track will be defined as one which is not at ground level (presumably below ARTS coverage); and which does not associate at least three times in a row with an ARTS track (or associates for less than 50% of the time). Appendix A gives the details. Thus the analysis will begin by numbering each BCAS track, and then by looking at its association history to label it as a real track or as a phantom track.

5.2 Overall Performance Statistics

Having by this manner separated real tracks from phantom tracks, we can then provide overall performance statistics.

Since real BCAS tracks have been identified, their existence can be compared with the aircraft that ARTS tells us are there.* These are called BCAS Associated Aircraft Tracks. The data in Appendix A is summarized in Table 5-1. Here it is seen that BCAS tracks exist between 70 and 75 percent of the time on aircraft within 5 nmi range.** This table is the result of the system measured in a real environment with all the vagaries encountered in the field; it is lower than one might first hope to achieve. Section 6 will explore probable explanations for this performance.

Similarly, the phantom tracks have been characterized. Here the measure of performance is different from that of the associated

* If, in some period of time, ARTS drops its track on an aircraft and BCAS keeps on tracking, we count this as legitimate, since the fact that an aircraft existed was presumably established by the existence of an ARTS track over some period of time.

** In the terminal area, where these tests were run, the maximum range of interest for tracks is about 5 nmi. That is the range at which two aircraft approaching head-on at speeds of 300 knots each would be 30 seconds from impact.

TABLE 5-1

FRACTION OF BCAS ASSOCIATED AIRCRAFT TRACKS

RANGE (NMI)	ASSOCIATION RATIO
0-5	0.73
0-10	0.74
0-15	0.68

TABLE 5-2

PHANTOM TRACK RATE

RANGE (NMI)	TRACK RATE*
0-5	0.38
0-10	1.00
0-15	1.47

* Phantom track rate for any range interval is the number of phantom tracks each scan for that interval, divided by the total number of scans.

Phantom tracks typically persist for only one or two scans.

BCAS tracks, since phantoms are invariably short-lived. Instead, the phantom track rate is used, as shown in Table 5-2. This rate is computed as the number of phantom tracks observed on each scan divided by the total number of scans. Within a 5 nmi range it is seen that, on the average, there is a transient phantom track about one third of the time. Section 7 will discuss this result in more detail.

6. ANALYSIS OF HIGH DENSITY RESULTS FOR BCAS ASSOCIATED
AIRCRAFT TRACKS

The results of the Washington flights presented in Section 5 immediately lead one to speculation as to cause and effect relationships. This section will examine real tracks (excluding the phantom tracks), show some of these relationships, provide data on supporting experiments, and draw certain conclusions. A discussion on phantom tracks appears in Section 7.

There are three main factors that could affect the association performance, namely: synchronous garble, the RF link between aircraft, and the tracker logic and parameters. Each of these will be considered in turn.

6.1 Synchronous Garble

Three different observations were made to obtain some appreciation of the impact that synchronous garble had on the performance of real tracks: association as a function of overlapping replies, a comparison of the results with the Whisper-shout technique, and an evaluation with a simulator.

6.1.1 Association as a Function of Overlapping Replies

In order to obtain a measure of the variation of performance with the number of overlapping replies, a scan-by-scan technique was used. On every scan all of the ARTS tracks present were compared directly with all of the BCAS tracks present (regardless of whether later determined to be real or phantom). If an ARTS track could be associated with a BCAS track, it was called an association; otherwise, it was called a missed association. From this the association ratio was obtained.

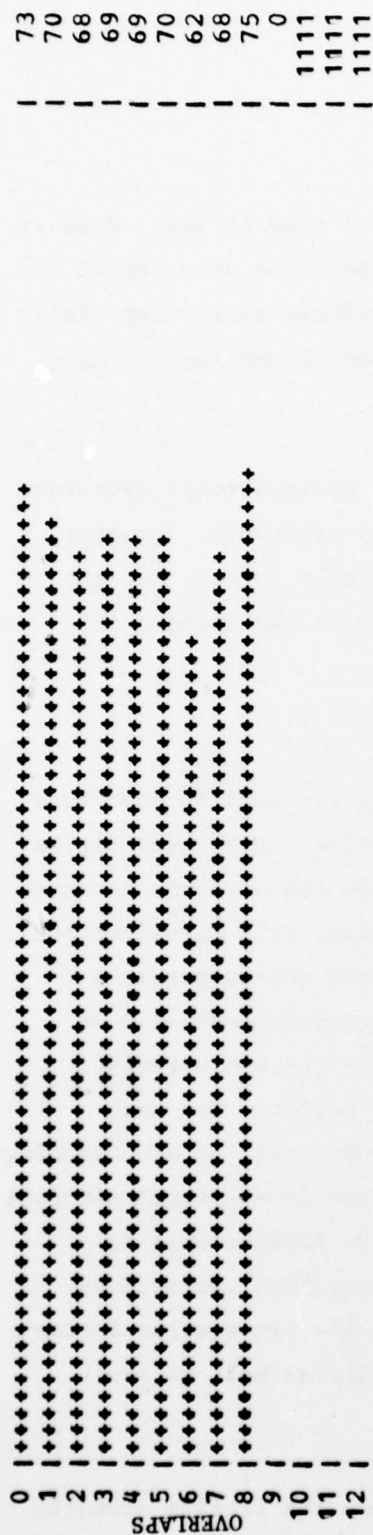
Then, also using the ARTS relative data, every track was inspected every scan to see how many other tracks were positioned within ± 1.65 nmi of it. This is the number of overlapping replies that BCAS would expect to see in response to its omnidirectional interrogations. To obtain these results we first eliminated all tracks which are beyond 10 nmi range or below 15 degrees depression angle, as seen from the BCAS aircraft.

The results are shown in Figure 6-1(a). It can be seen that there are two important features: the highest that the association ratio gets is about 73 percent (the 75 percent figure observed for eight overlaps does not have many data points), and the degradation with the number of overlaps, though apparent, is relatively small. This implies that the tracker is doing its job in reading through many overlapping replies. The original design goal was to work through approximately seven overlaps. While some degradation with increasing overlaps is observed, the fairly constant figure, on the order of 70 percent, appears from this observation, to be caused by factors other than synchronous garble.

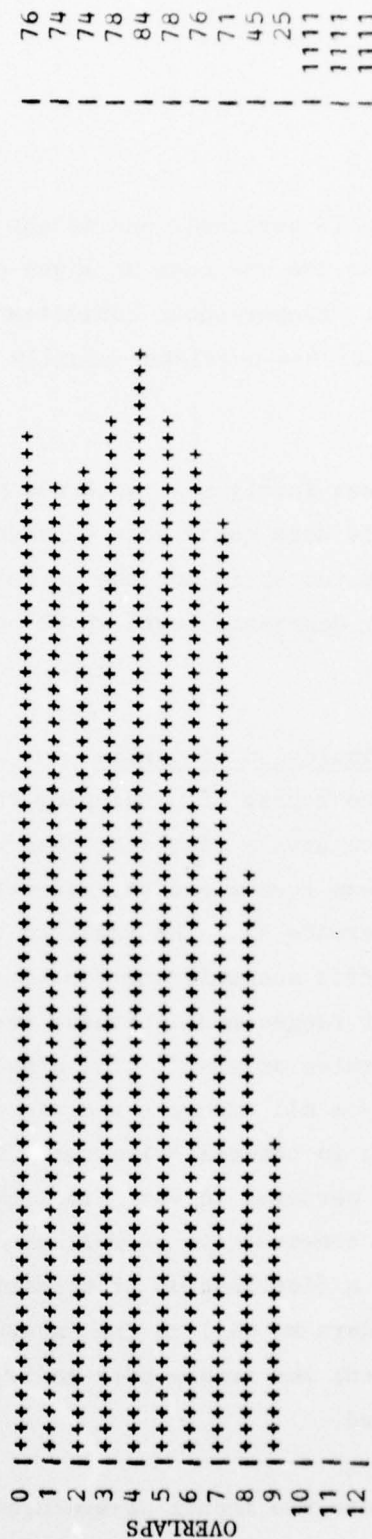
6.1.2 Comparison with Whisper-Shout Technique

As noted earlier the Whisper-shout technique was conceived in order to reduce the number of overlapping replies encountered from any one omnidirectional interrogation. If synchronous garble is a substantial factor in reducing the association ratio, then we would expect a large improvement when using the Whisper-shout technique.

Figure 6-1(b) shows the resulting ARTS association ratio as a function of the number of overlaps. For zero overlaps Whisper-shout is seen to be somewhat better than Basic; the amount is



a) BASIC



b) WHISPER-SHOUT

NOTE: DATA TRUNCATED AT 10 NMI AND -15° .

FIGURE 6-1
RATIO OF SAMPLES OF ARTS TRACKS ASSOCIATED WITH BCAS TRACKS

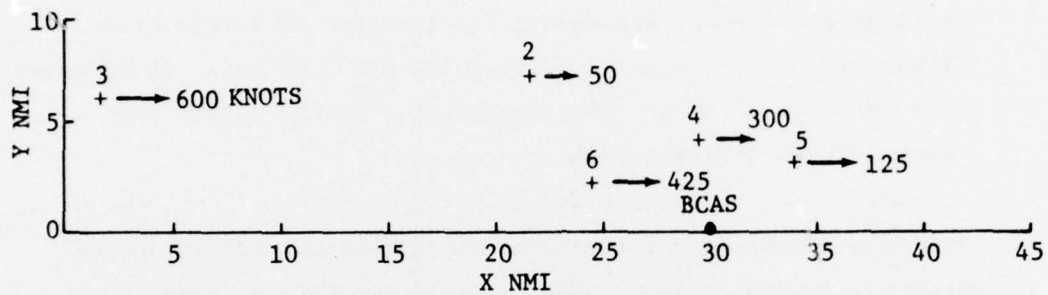
not large (3 percent), and is not considered significant. However, except for the one case at eight overlaps where the data sample is small, Whisper-shout consistently outperforms Basic, especially in range of 4-6 overlaps--usually by at least 10 percent in that region.

This agrees fairly well with the preceding observations; synchronous garble does cause some degradation in performance. However, the major factor is not the variation caused by garble, but the generally depressed level which occurs even in the absence of overlaps.

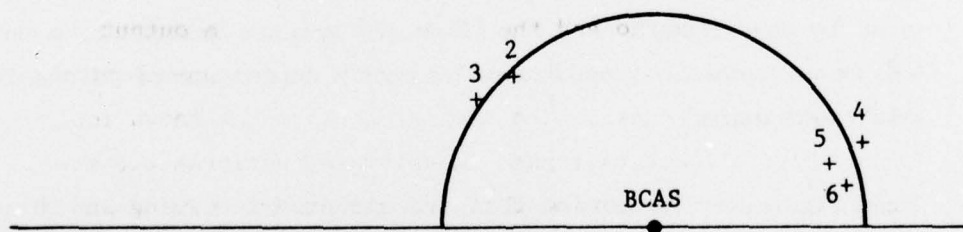
6.1.3 Simulation of Garble

During the course of developing the tracker for BCAS it was found helpful to have a simulator that would provide a simulated digital data stream equivalent to that obtained from the airborne hardware (see Reference 4). The input to the simulator is a specification of a traffic scenario and the RF environment; the output is a buffer of ranges and altitudes for every detection--phantom or real, garbled or clear. The simulator takes the known reply trains from all aircraft and, in software, performs the same functions in non-real-time that the airborne receiving and decoding hardware performs in real time. Where pulses from several aircraft overlap, constructive as well as destructive interference is modeled; a distribution of transmitter powers from the various transponders as well as the inverse-square-law propagation factor is modeled; and transponder reply probability as well as fruit is modeled.

To evaluate the impact of synchronous garble the traffic scenario of Figure 6-2(a) was devised. The BCAS aircraft is shown stationary (for convenience) at 30 miles on the X axis; five other



a) INITIAL CONDITIONS



b) 20 SECONDS LATER

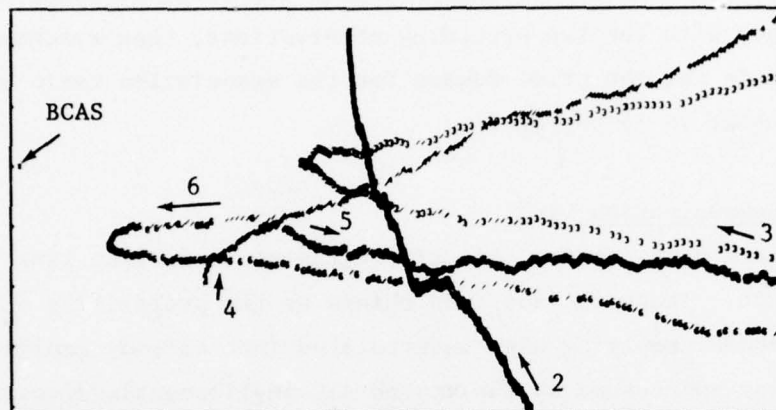
FIGURE 6-2
SIMULATED TRAFFIC SCENARIO

aircraft at various speeds are traveling parallel to the X axis. After 20 seconds, the situation changes to that of Figure 6-2(b), where the replies from the five aircraft go through a period of intense overlap. Subsequently the period of intense overlap disappears, but occasional overlapping still occurs. In addition to a vertical velocity, some degree of vertical jitter was assumed in the traffic model.

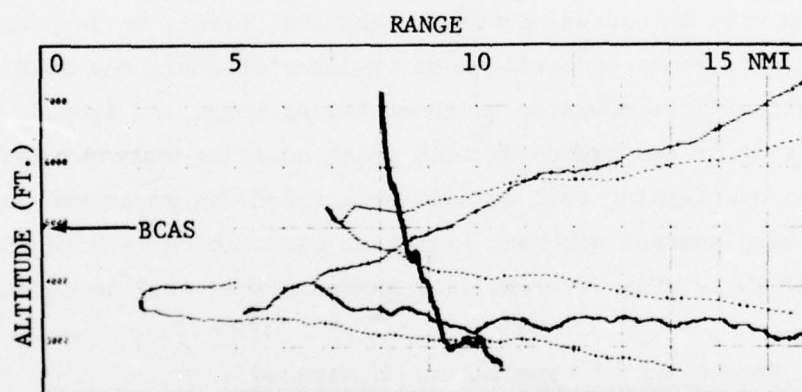
Figure 6-3(a) shows the input to the simulator with the above traffic scenario. Range from the BCAS aircraft is plotted on the abscissa; altitude is on the ordinate, with the altitude of the BCAS aircraft constant at 5000 feet. As each aircraft proceeds on its course, a number is plotted indicating the true position of that aircraft at that instant. If a space appears instead of a number, the aircraft did not reply because it was either already replying to a ground interrogator, or was suppressed by the ground (a transponder reply probability of 90 percent was used in this example). If a slash (/) appears instead of a number, the conditions for garble were present (usually extra pulses in the reply train).

From Figure 6-2 we know that when aircraft No. 3 is about 10 nmi away from the BCAS aircraft, the intense garble condition exists. Figure 6-3(a) shows that region as one in which many slashes appear--most easily seen on targets 3, 4 and 6.

Figure 6-3(b) shows the output of the actual BCAS tracker (simulated flight hardware and actual software) after it operates on the simulated buffers. The display is to the same scale as before; a dash (-) indicates that an update was received, a plus (+) indicates a coast.



a) BCAS SIMULATOR



b) BCAS TRACKER

FIGURE 6-3
SIMULATION OF BCAS ABILITY TO HOLD TRACK THROUGH GARBLE

It can be seen that the tracker is able to hold and update quite well through the severe garble. This too tends to confirm, together with the two preceding observations, that synchronous garble is not the prime reason for the association ratio being only about 70-75 percent.

6.2 Communication Link

There are many factors that affect the communication link between aircraft. These include such things as the probability of a transponder replying when interrogated (not already replying to or being suppressed by the ground ATC environment), aircraft antenna shielding, power budget, interrogation protocol, and ground reflections. All of these factors vary over wide ranges through a flight. Three means of assessing the viability of the RF link will be discussed here: they are, first, an inspection of the difference in performance of aircraft above the BCAS aircraft will be compared to those flying below it; second, an inspection of the degree of BCAS track coasting when replies are not overlapping will be made and, third, an experiment at NAFEC with another aircraft flying at many altitudes both above and below the BCAS aircraft (one-on-one tests) will be discussed.

6.2.1 Dependence of Association on Altitude

We have already seen that in traffic conditions represented by flights over the Washington TCA, the ratio of BCAS associated aircraft tracks within 5 miles of the BCAS aircraft is 73 percent. Recall that to obtain the BCAS associated aircraft tracks we first define and remove phantom tracks, identify aircraft tracks by ARTS data, and then associate the BCAS track to those aircraft tracks. If we inspect the performance as a function of both relative range and relative altitude, we obtain the results of Figure 6-4. The most significant trend is that for the other aircraft within 5 nmi of our BCAS aircraft the performance is much better if they are

RELATIVE ALTITUDE (K FT.)

	RANGE (NMI)			RANGE (NMI)		
	0-5	6-10	11-15	0-5	0-10	0-15
> 5	.87	.83	.84	.87	.84	.84
0 TO 5	.97	.90	.66	.97	.92	.79
0 TO -5	.72	.68	.51	.72	.69	.60
< -5	.65	.71	.67	.65	.69	.68

ABOVE

BELOW

REGION OF INTEREST
IN TERMINAL AREA

a) ASSOCIATION IN 5-NMI INCREMENTS

b) CUMULATIVE ASSOCIATION

NOTE: THE DATA REPRESENTS ABOUT 350 TRACKS.

c) CUMULATIVE ASSOCIATION FOR ALL
ALTITUDES

.73	.74	.68
-----	-----	-----

FIGURE 6-4
ASSOCIATION DATA FOR BASIC MODE

above us than below us. This may be expected, since their transponder antennas are invariably mounted beneath their aircraft. The BCAS aircraft interrogates both from a top antenna and a bottom antenna, as was stated earlier. Figures 6-4(b) and (c) are cumulative with respect to range, the intervals being from zero to the designated value.

The data given here represents about 350 tracks over the period of time. With the exception of the box representing very high altitudes and close range there were more than 250 data samples per box--in some cases, more than 10 times that many. For that one box, there were only 45 samples, so its result (0.87) is less certain.

Figure 6-4 strongly indicates that aircraft antenna shielding is an important factor in the system. Other factors, however must not be overlooked.

6.2.2 BCAS Track Correlation

When a BCAS track is formed, it is projected ahead one second. If the next reply closely matches, or correlates, with the projection, the track is updated; if not, the track is coasted (Reference 5). Also, on each scan we attempt to associate a BCAS track with an ARTS track. If it does associate, we look at other ARTS tracks to determine how many overlaps exist, as we did in Section 6.1.1. Here we will look only at associated BCAS tracks and inspect the correlation, or coasting, performance of those tracks. If we choose only those tracks for which there is no interference from other overlapping tracks, then the correlation ratio should be equal to the garble-free round reliability of the system. As in Section 6.1.1, we first

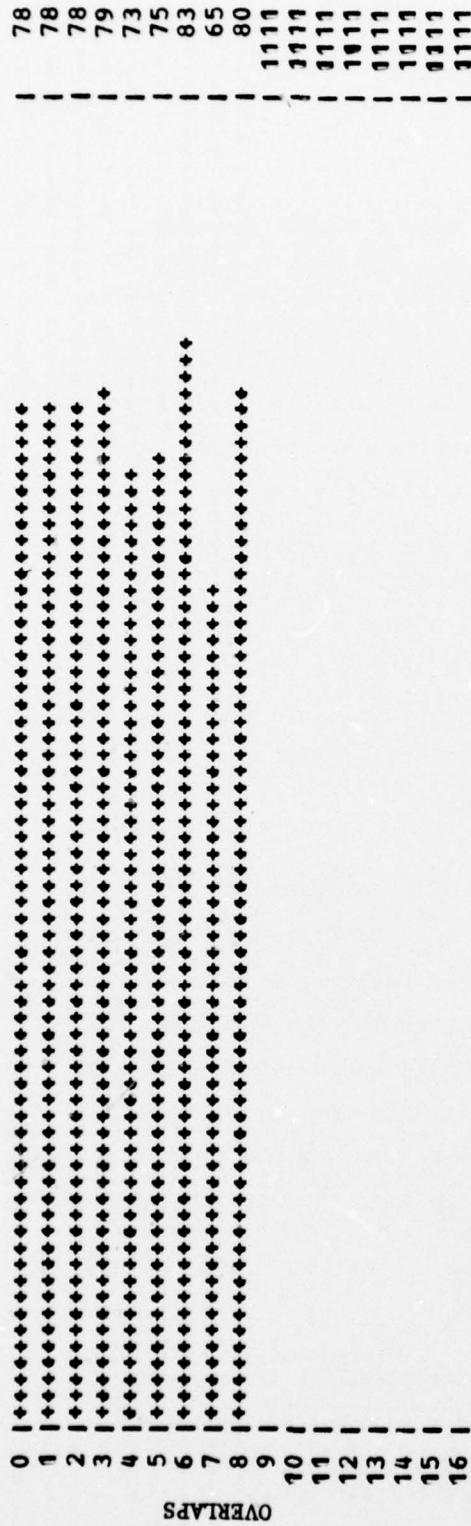
eliminated tracks that were beyond 10 nmi in range or below 15 degrees depression angle, as seen from the BCAS aircraft.

Figure 6-5(a) shows the measured correlation of these clear, associated BCAS tracks. The correlation is seen to be 78 percent, which appears to be much too low to ascribe only to reply probability (probability that transponder will reply, given a sufficiently strong interrogation). Normally, the reply probability may be expected to be greater than 95 percent (Reference 6). From this we may infer, that a poor reply probability is not the explanation for the behavior of the association ratio-- it could not be that low without ARTS noticing it. However, the fact that the BCAS coasting is substantial increases the susceptibility to other forms of perturbations.

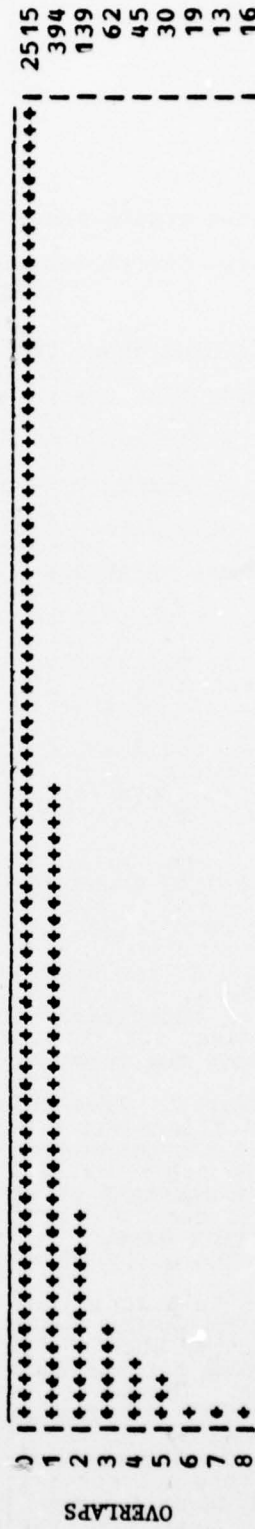
Figure 6-5(b) shows another aspect of BCAS correlation. This view of correlation does not separate the associated BCAS tracks according to the number of overlaps, but rather according to the number of sequential BCAS coasts. Thus there were 394 instances where only one coast existed and 139 cases where two coasts in a row occurred. From this it can be estimated that interrogating at twice the present one-second rate would reduce the coasting to about one-half of its present value. This will be examined at a future date.

6.2.3 One-on-One Tests at NAFEC

To provide further data on the communication link than could be obtained with the many uncontrolled variables encountered in the Washington test, another flight series was run in a more controlled environment near NAFEC.



a) CORRELATION VS. OVERLAPS



b) CORRELATION VS. NUMBER OF CONSECUTIVE COASTS

NOTE: DATA TRUNCATED AT 10 NMI AND -15°

FIGURE 6-5
CORRELATION CHARACTERISTICS OF ASSOCIATED BCAS TRACKS (BASIC SYSTEM)

Appendix B shows graphically the track plots on the range-altitude plane as they were recorded at NAFEC. The flight scenario was for the target aircraft (transponder only) to fly at 1000-foot increments above and below the BCAS aircraft. Each altitude was traversed twice--once with a head-on approach, and once with a 90° approach. A total of 16 runs were made from 4000 feet below, to 4000 feet above the BCAS aircraft. Because of changing weather conditions the original plan, which would have had one complete series with the BCAS at 5500 feet and another with it at 7500 feet, had to be curtailed. Instead, the BCAS aircraft flew at 5500 feet when the target aircraft was below it, and at 7500 feet when the target aircraft was above it.

The tracks in Appendix B are divided into inbound and outbound segments, and they are summarized in Figure 6-6. The inbound segments are shown on the left half of the figure; the outbound segments are on the right. The lines depict those portions of the flight where the tracks existed; solid lines are the head-on encounters, dotted lines are the crossing encounters. When a track died, the line is terminated by an X.

Several things are evident from these summary figures. First, when the other aircraft is below the BCAS aircraft, the performance is decidedly poorer than when it is above--particularly so for the outbound portion of head-on encounters. Also notable is that in practically all cases the track on the lower aircraft was dropped when the depression angle to it exceeded about 30 degrees. The poorer performance of the outbound encounters is explained by the fact that there is an acquisition time necessary to restore a track after it has been dropped. Also, for the head-on case, the transponder antenna on the target aircraft is located near the nose of the aircraft.

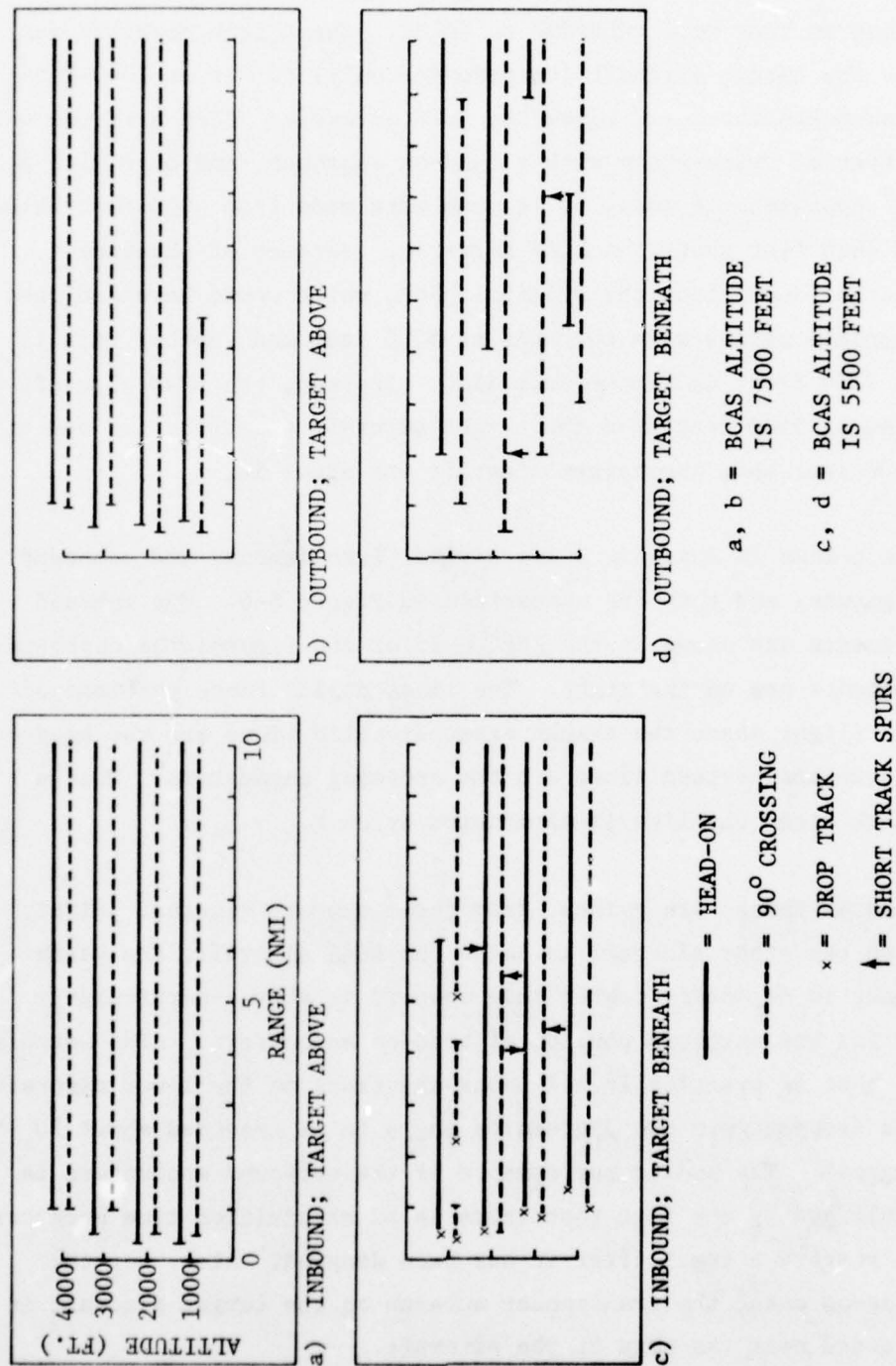


FIGURE 6-6
SUMMARY OF ONE-ON-ONE TRACKS FOR FLIGHTS AT NAFEC

The much better performance when the target aircraft is above the BCAS aircraft is evident from the fact that there are no dropped tracks anywhere.

Combining all the data summarized by Figure 6-6, one obtains the overall results of Table 6-1. The "above" performance is excellent; the "below" performance is 81 percent. That is, 81 percent of the time the data was being recorded, and when the target aircraft was within 10 nmi of BCAS, the target aircraft was being tracked. These figures generally agree with those of Figure 6-4, and point very strongly to aircraft antenna shielding as being a major cause for the degraded performance when the other aircraft is lower than the BCAS.

6.2.4 Ground Reflections

Another factor that is apparent when studying the data of the NAFEC one-on-one tests is the influence of ground reflections. When the target aircraft was below the BCAS, two instances of severe multipath and a number of cases of incidental multipath were noted. From Figure 6-6, the inbound segment of the crossing approach at 1000 feet below the BCAS shows that the track was dropped twice--at about 5.5 nmi and at about 2.5 nmi.

Inspecting the recorded reply buffers showed that the drop at 5.5 nmi was caused by a garbled altitude code. The tracker showed no evidence of any other aircraft within garbling range, so the inference is drawn that the ground-reflected signal is causing the interference. From noting the altitudes and relative range one can calculate the resulting time delay--it is from 1 to 1-1/4 μ s. The tracker should read through this garble, much as it was able to do so in Figure 6-3, even though the "relative motion" between direct and reflected replies is slow. The fact

TABLE 6-1
TRACKING PERFORMANCE AT NAFEC

	INBOUND	OUTBOUND	TOTAL
Above	1.00	1.00	1.00
Beneath	0.94	0.67	0.81

that the reply was garbled in this instance is not fully explained at this time--it leads one to suspect, among other things, some malfunction in the decoder. A further analysis will be made.

A typical treatment of ground reflection by the tracker is shown in Figure 6-7. The vertically moving track at about 3 nmi is seen to be followed by its delayed reflection for some period of time. Such a delayed track has no impact on the threat detector.

The track loss at 2.5 nmi was of a completely different character. Inspecting the reply buffers here showed no replies at all--garbled or otherwise. The computed time delay when the replies actually stopped, which occurred at a range of 3.5 nmi, is 2.2 μ s. This is very close to the delay that would cause a suppressed interrogation. That is, the transponder, on receiving the reflected P_1 , would treat it as a P_2 suppression pulse and not reply when P_3 finally arrives.

These severe evidences of multipath as manifest by dropped tracks were apparent only twice in all of the tests. It is likely, although not confirmed, that this particular flight path was over water as the test locale was near the New Jersey shore.

Other, much less significant, evidence of multipath was observed from the data. These cases were shown by the generation of short offshoots from the main track but very close to it (these are recognized and disregarded by subsequent merge logic). The location of these offshoots are indicated by the arrows in Figure 6-6. Significantly, no evidence of multipath interfering with a track was observed for the target aircraft above the BCAS aircraft. In that case, the direct path from the top BCAS

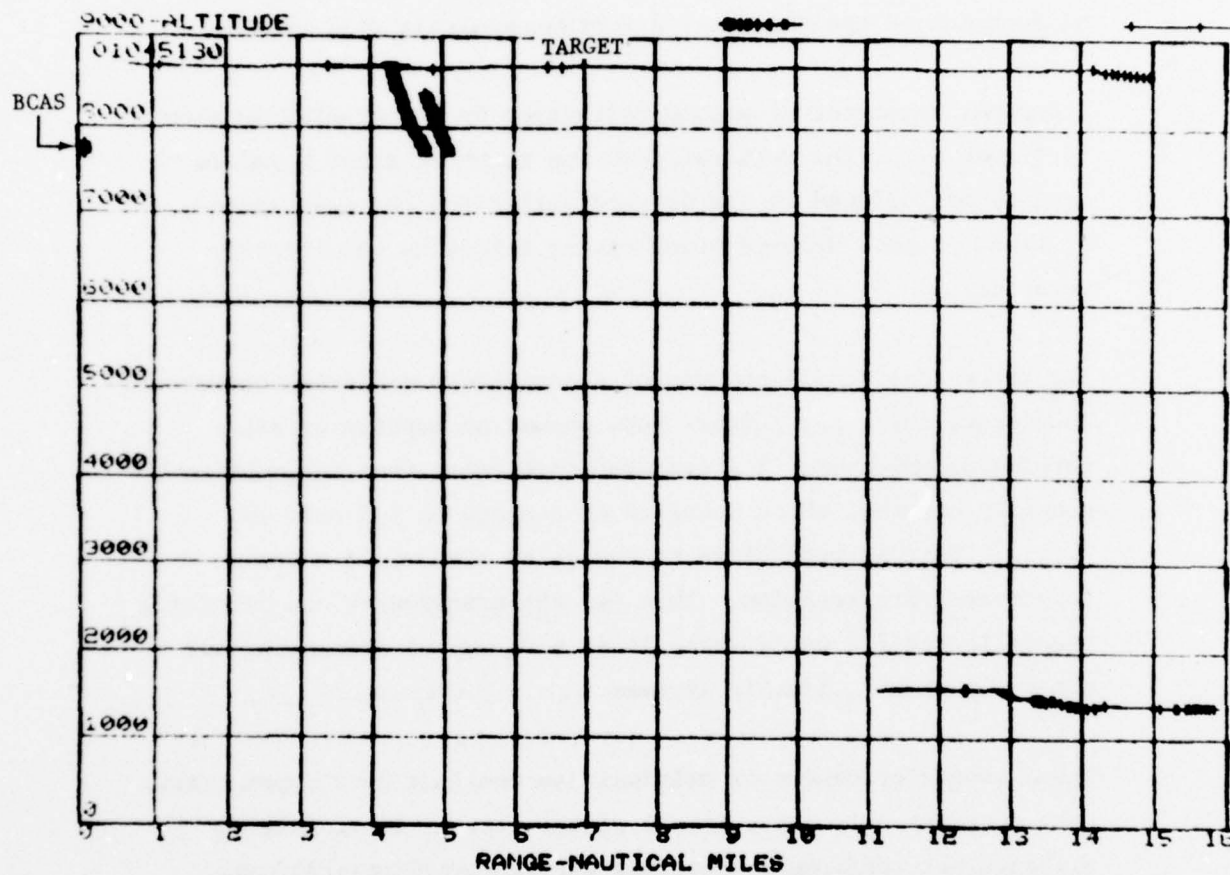


FIGURE 6-7
OUTBOUND HEAD-ON ENCOUNTER (+1000 FT.)

antenna to the target aircraft's bottom-mounted transponder antenna is always stronger than the indirect, ground-reflected path which is shielded by the BCAS fuselage and further attenuated by the ground reflection coefficient. Just the opposite situation exists for the target aircraft below the BCAS aircraft, where the direct path is shielded by the target aircraft's fuselage.

The evidence of ground reflections must also be coupled with its significance on the data. Except for the two dropouts noted earlier, the tracker was able to hold on to the track and caused no degradation. Thus ground reflections, while apparent, are judged to have a minor impact on the overall data quality.

6.2.5 Power Budget and Interrogator Protocol

The power budget figures are given in Appendix C for a 10 nmi range. Using the nominal figures for a transponder, the interrogation link (1030 MHz) has a 5 dB more margin than the return link (1090 MHz). This was done purposely to ensure that all aircraft were being interrogated. The interrogation range of a nominal transponder is thus slightly more than 30 nmi, while the range at which its replies can be heard is slightly less than 20 nmi.

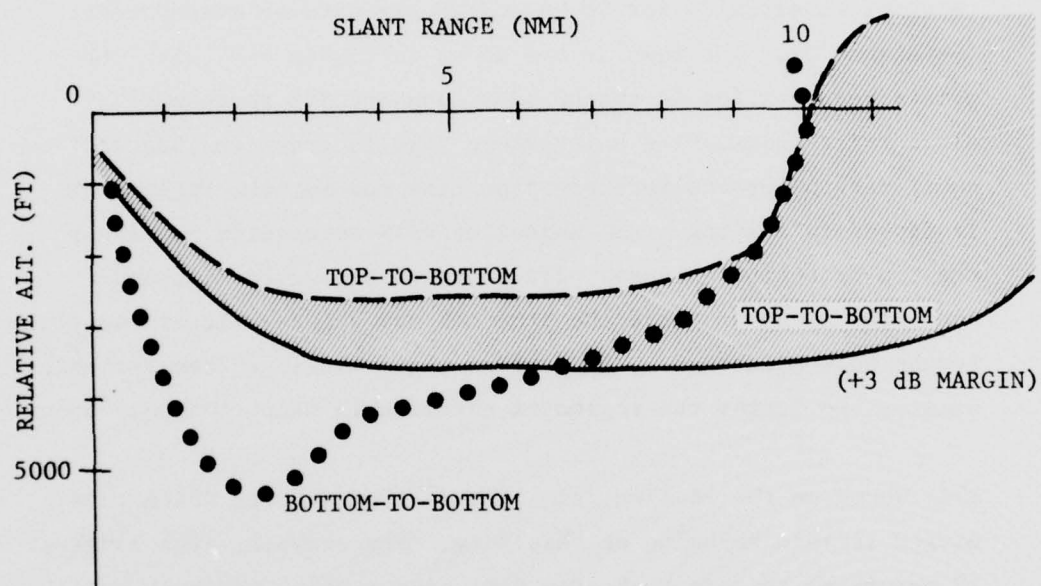
It has recently been appreciated, however, that the link margins interact with the particular interrogation protocol that was used, so as to introduce a possible suppression effect. Recall that the interrogation protocol in the Basic design is as follows: first, interrogate from the top antenna and process the replies; then send a suppression pulse pair from the top, immediately followed by an interrogation from the bottom antenna. The

purpose of this protocol is both to avoid the interference that would be introduced by having all transponders reply to the two interrogations, and to avoid the processing necessary to merge the tracks that would result if they all did reply to the two interrogations.

However, if the interrogation link is stronger than the reply link, there are regions of airspace in which the transponder could hear and reply to the top interrogation, but the reply would not be received. The subsequent interrogation would first suppress that transponder, so no reply would be received from either the top or the bottom interrogation. If, on the other hand, the interrogation link is matched to the reply link, there is no region of airspace in which this condition could occur.

A pictorial explanation of this process is shown in Figure 6-8, where typical antenna patterns were abstracted from Reference 7. The coverage of the top antenna for a link with zero dB margin at 10 nmi is shown as the dashed line--think of this as the coverage of the reply link. If the interrogator link from the top antenna is 3 dB stronger, its coverage would be the solid line. Aircraft within the solid line would reply, but they would not be heard unless they were also within the dashed line. The shaded area represents the volume of airspace that concerns us here.

The dotted line shows the reply link coverage when the bottom antenna is used. The aircraft falling within the dotted line could ordinarily be heard. However, the aircraft that are within the dotted line and that are also in the shaded region will have been suppressed by the interrogation protocol, so they will not be seen on either antenna.



NOTE: Pattern characteristics are averaged over all aspect angles and for 727, Gulfstream, and Beach 99 (Reference 7)

FIGURE 6-8
GENERIC ANTENNA COVERAGE PATTERNS

The link margin is determined partly by the BCAS interrogator-receiver and partly by the transponder's transmitter and receiver. To assess the implication that this link-margin criterion might have on our results, we have plotted the transmitter power and receiver sensitivity for 50 GA and 28 air carrier transponders (Reference 8). The results are shown in Figure 6-9, with the points representing GA transponders and the X's representing air carrier units. The unity-slope line is drawn to indicate equal margin for the interrogation link and for the reply link. Transponders falling below this line will be covered by either the top or bottom antenna. Transponders above the line may encounter airspace where the protocol may suppress their replying to the bottom antenna. The farther above the line that the point exists, the larger the region of airspace in which this may occur.

Also shown on the equal-margin line is the range at which this margin is zero assuming no shielding. For example, at a range of 10 nmi there is seen to be one transponder which has both a receiver sensitivity sufficient to receive the interrogation (it lies above the horizontal line) and a transmitter power that is insufficient to be heard (it lies to the left of the vertical line). This defines a suppression region on the plot. As the range decreases the zero margin point moves down and to the left along the equal margin line, thereby enabling communication with more transponders; as the shielding increases, the point moves up and to the right, excluding more transponders.

The transponder marked with a square represents the measured characteristics of the transponder on the target aircraft for the NAFEC one-on-one tests. That transponder lies above the equal margin line, so it is a candidate for this suppression phenomenon. However, at 10 nmi range, 8 dB of shielding could be introduced

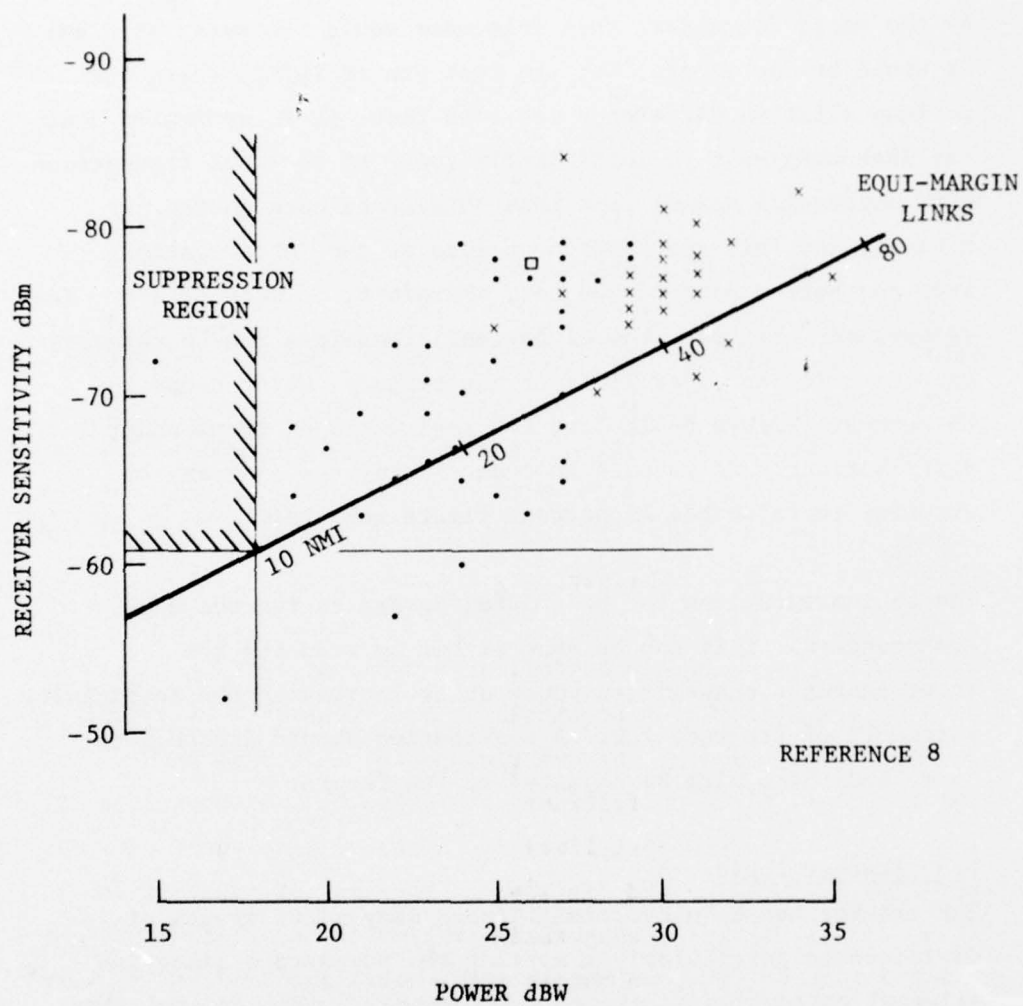


FIGURE 6-9
MEASURED TRANSPONDER CHARACTERISTICS

before the suppression region would encompass the transponder. As the range decreases, this tolerance would increase, at 5 nmi it would become 14 dB. For the test run at NAFEC, where the maximum altitude difference was 4000 feet, it is estimated that the link margins were sufficiently great so that all transaction with depression angles less than 30 degrees were on the top antenna, and this suppression of some of the interrogations from the bottom antenna was not, therefore, of much effect. The results of Table 6-1 (the 81 percent) therefore can be taken as approximating an upper limit of performance, which drops to 73 percent (Figure 6-4(b)) in the real world of transponder distributions. So we note that equalizing the link may be expected to raise the 73 percent figure somewhat.

The equi-margin line can be shifted upward to include more transponders. This can be done either by reducing the interrogator's transmitted power or by increasing the sensitivity threshold of its receiver. A combination should probably be done, and these will be adjusted in the future.

6.3 Tracker Logic

The tracker has been evolving through many minor stages of improvements particularly in setting the parameters since its original conception as given in Reference 2. The general form, however has remained, and the flowcharts shown in Reference 5 are still for the most part valid. The version of software used in the data collection series reported here is identified as WLPRC-3.

The tracker performance has been verified by simulation in the laboratory, as noted earlier. Both performance in garble and ability to hold track through rapidly changing range rates were examined and found to be satisfactory. It is concluded

that while improvements in the tracker still can be effective, it is not a major factor in accounting for the 73 percent association.

6.4 Summary of Analysis of Association Performance

It has been shown that this active ATCRBS mode of BCAS will have tracks between 70 and 75 percent of the time on aircraft that are within 5 nmi range. The performance is essentially perfect for aircraft above the BCAS aircraft and degrades to 72 percent for aircraft below. The major cause of the degradation is ascribed to aircraft antenna shielding, influenced to some extent by the interrogator protocol. It has also been determined that ground reflections, synchronous garble, and tracker logic are minor contributors to this phenomenon.

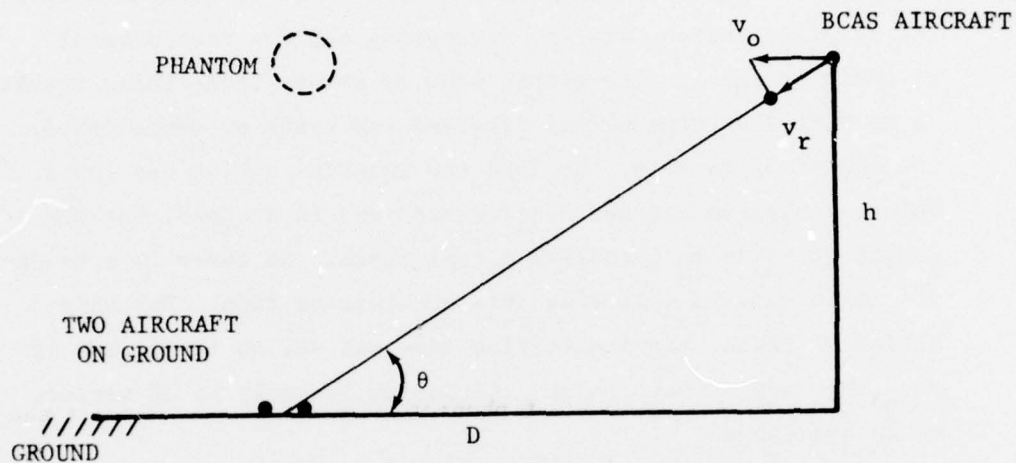
7. ANALYSIS OF HIGH DENSITY RESULTS FOR PHANTOM TRACKS

As noted in Section 5, phantom tracks tend to be generated when the relative motion between overlapping replies from several aircraft is small. The method used to remove these false tracks is to wait some time before treating any track as established. The longer it is held, the less the relative motion has to be before a phantom becomes decorrelated and is dropped, but the longer it takes to establish a real track. So there is a trade-off to be made in selecting this acquisition time. For this series of tests, the acquisition time was set to 10 seconds if the track was at zero range, increasing linearly to 30 seconds at 20 nmi range.

As noted before phantom tracks most frequently are generated from stationary or slowly moving aircraft on the ground. The concern of the phantom track is that the aircraft on the ground might appear to be at the altitude of the BCAS aircraft and erroneously be regarded as a threat. Figure 7-1 shows the geometric relationships. The BCAS aircraft traveling at velocity v_0 encounters a phantom track caused by aircraft on the ground at distance D , but with a garbled altitude.

We can calculate the relation between altitude and velocity that is necessary to cause a τ^* of 30 seconds, the typical alert time. Knowing that τ is a minimum when the angle θ is 45° , the relation in Figure 7-1 is obtained. Thus at maximum permissible speeds in the terminal area, this source of phantom tracks will not cause an alarm if the BCAS aircraft is at least one mile above ground level.

* τ is equal to the range divided by the range-rate. It corresponds to time to collision for two aircraft on a collision course.



[h] = FEET
[v] = KNOTS

$$\tau = \frac{\sqrt{h^2 + D^2}}{v_r}$$

τ_{\min} occurs when $\theta = 45^\circ$

$$\tau_{\min} = \frac{h\sqrt{2}}{v_o/\sqrt{2}} = \frac{2h}{v_o} = 30 \text{ s}$$

$$h = v_o \left(\frac{6080 \text{ ft}}{3600 \text{ s}} \right) \times \frac{30}{2} \text{ s} = 25.3 v_o$$

e.g., $v_o = 250$ knots, $h = 6333$ feet.

FIGURE 7-1
PHANTOMS GENERATED BY AIRCRAFT ON GROUND

In addition to the observation that, within 5 nmi, there is a phantom track about one-third of the time, these tracks were examined to determine how often the tracks were found to be within +5000 feet in altitude of the BCAS aircraft and to have a Tau of less than 40 seconds (this is purposely larger than the threat window of about +3000 feet and 30 seconds). This was also compared with real tracks appearing in that same window. The result was that 124 scans of real tracks appeared in the window, whereas only 25 scans of phantom tracks were present.

Though there were a number of phantom tracks that penetrated the window they were there for only a short time (typically one or two scans). Examining these phantom scans further, it was found that all were within 5 nmi of the BCAS aircraft. This suggests that the acquisition time for these close-in aircraft has been reduced too far. This will be reviewed at a future date.

APPENDIX A

DATA COLLECTED IN WASHINGTON, D.C. AREA

A.1 Introduction

The data presented in this Appendix comes from the data reduction package mentioned in Section 2. It is principally a comparison of BCAS tracks with the tracks obtained by using the target reports from ARTS III data tapes in the Washington flights.

First, an overall view of the system is shown by a series of matrices for "real" BCAS tracks and for "phantom" BCAS tracks. This is followed by detailed tables and histograms of performance with such parameters as the number of overlapping replies and the density of aircraft in the airspace. The figures for this section will be found grouped together at the end of the section.

A.2 Overall Performance Characteristics

The Total Aircraft Track Matrix lists, for each scan and in each range-altitude bin, the number of tracked aircraft events obtained during the comparison interval. An aircraft track is determined principally by the presence of an ARTS track; however, if the ARTS track is lost and the corresponding BCAS track continues, the aircraft track is also continued. Thus an "aircraft track" implies a continuous process; whereas, an ARTS track is often a segmented process.

Total Aircraft Tracks are described by two matrices:

1. Range versus Altitude Matrix, denoted $A(r,z)$ (Figure A-1)

where \bar{r} - is the integerized range of an ARTS* track:

$\bar{r} = \text{INTEGER}(r) + 1$; this implies that the range of a track is, at most, r nautical miles from BCAS aircraft.

\bar{z} - is the relative altitude quantized into 500 foot bins.

$$\bar{z} = (\text{BCASALT MINUS THREAT ALT PLUS } 10,000)/500;$$

e.g., suppose an aircraft is 5.597 nautical miles away from our BCAS equipped aircraft and has an altitude of 12,000 feet. Let BCAS altitude = 7,300 feet.

$$\text{Then } \bar{r} = 5.597 + 1 = 6$$

$$\bar{z} = (7,300 - 12,000 + 10,000)/500 = 4800/500 = 9.6 = 10$$

So (\bar{r}, \bar{z}) is put in the \bar{r}, \bar{z} slot of $A(r,z)$.

Any aircraft having relative altitude, greater than 10,000 feet is counted as relative 10,000 feet.

2. Range versus Range Rate Matrix, denoted as $JKR(r,k)$ (Figure A-2)

where \bar{r} - is the integerized range of an ARTS track;

\bar{k} - is the range rate in knots of an ARTS track quantized into 30 knot bins.

$$\bar{k} = (\text{Range rate of threat aircraft} * 3,600 + 600)/30;$$

* As previously noted, the BCAS range is used in certain instances, when an ARTS track is lost.

e.g., let 3.79 be the relative range of a threat aircraft and -0.056 be its range rate (nmi/sec).

Then $\bar{r} = \text{INTEGER}(3.79) + 1 = 4$

$\bar{k} = (-0.056 * 3,600 + 600)/30 = 13.28 = 13$

So (\bar{r}, \bar{k}) is put in the \bar{r}, \bar{k} slot of $\text{JKR}(\bar{r}, \bar{k})$.

Criteria for Track Association of a BCAS track with an ARTS track are as follows:

1. $\text{ABS}(\rho_B - \rho_A) < R_{\text{WIN}}$ & $\text{ABS}(Z_B - Z_A) < H_{\text{WIN}}$
where ρ_B is relative range of aircraft being tracked by BCAS and ρ_A is relative range of ARTS aircraft;
 R_{WIN} is range window. H_{WIN} is altitude window. Z_B is altitude of aircraft being tracked by BCAS and Z_A is the altitude of an aircraft being tracked by the ARTS site (i.e., Washington National). R_{WIN} is set initially to 0.99 nmi and H_{WIN} is set initially to 299 feet.
2. Both ARTS tracks and BCAS tracks must be established.
An ARTS track is considered to be established when it reaches an age of 30 seconds, unless an established BCAS track associates with it, in which case two successive ARTS reports are required in order for the track to become established. BCAS tracks are established at an age of 10 seconds, increasing linearly with range to a maximum of 30 seconds at 20 nmi.

Total BCAS Associated Aircraft Track Matrices represent the total number of BCAS tracks* that were successfully associated with corresponding aircraft tracks during the course of the comparison interval. There are two associated BCAS track matrices. They are as follows:

1. Range vs. ALT matrix (Figure A-3) - denoted $ASC(r,z)$ where r,z represents the range and altitude of an ARTS track with which a BCAS track successfully associates. However, if the ARTS track is temporarily lost, the r and z of the associated BCAS track is used.

$$ASC(r,z) \subseteq A(r,z)$$

2. Range vs. Range Rate matrix (Figure A-4) - denoted $RATE(r,k)$ where r,k represents the range and speed of an ARTS track with which a BCAS track successfully associates.

$$RATE(r,k) \subseteq JKR(r,k)$$

Ratio of BCAS Associated Aircraft Tracks to Total Aircraft Tracks gives the ratios of the preceding matrices and indicate the overall capability of BCAS to track aircraft within a radius of 20 nmi. These appear as Figures A-5 and A-6.

ARTS - BCAS Track Association Summary Tables (on a per mile basis) can be defined in the following way:

$$R_n = \sum_{n=1}^{20} B_n / A_n$$

* Here, BCAS tracks are those which remain after removing phantom tracks (see Section 6).

where B_n is the number of times a BCAS track associated with an aircraft track whose range was n nmi, and A_n is the total number of aircraft tracks at n nmi (Figures A-7 through A-9).

Cumulative Summary Table of BCAS associated aircraft tracks to total aircraft tracks (Figure A-10) is defined as follows:

$$\text{Cumulative ratio} = \sum_{S=1}^{20} (B_S + B_K) / (A_S + A_K)$$

where B_S , number of times a BCAS track associated with an aircraft track whose range was S nmi.

$$B_K = \sum_{J=1}^{S-1} B_J, \text{ total number of times a BCAS track associated with an aircraft track from 1 to } (S-1) \text{ nmi.}$$

A_S , total number of aircraft tracks at S nmi.

$$A_K = \sum_{J=1}^{S-1} A_J, \text{ total number of aircraft tracks from 1 to } (S-1) \text{ nmi.}$$

Note: If $S-1 = 0$, then $B_K, A_K = 0$.

Phantom Probability Matrix (Figures A-11 and A-12) contains those BCAS tracks that have been defined as being phantoms.

1. Any BCAS track with no association history at all is considered to be a phantom.
2. Any BCAS track not having either three consecutive associations, or at least 50 percent association, is also labeled as being a phantom.

Each entry consists of the number of scans that phantom tracks were found to exist divided by the total number of scans. If a BCAS track is found to be a phantom track, its entire track history is put into the phantom matrix. In addition, the association matrix is also modified, thus removing phantoms from it.

A.3 Detailed Tables and Histograms

The preceding paragraphs provide the overall performance of BCAS. In order to understand some of the underlying relationships various other analyses were made. The following paragraphs examine the variation of performance with two major parameters, the number of overlapping replies and the number of aircraft in the airspace. These tables were compiled directly from ARTS and BCAS track data. No attempt was made here to distinguish between real and phantom tracks. In general, the results with the Basic system are presented first, followed by those for the Whisper-shout system.

The Track density table of ARTS peak traffic conditions

(table A-1) provides the following for established ARTS tracks:

1. The range within which the indicated maximum number of overlaps occurs, and the time at which it occurs.
2. The range within which the indicated maximum number of aircraft (ARTS tracks only) occurs, and the time at which it occurs.

TABLE A-1
PEAK TRAFFIC CONDITIONS

RANGE	MAX OVERLAPS	TIME	MAX AIRCRAFT	TIME
2.50	3	53463	4	54602
5.00	5	52512	5	52512
7.50	7	53877	10	52071
10.00	9	52559	14	52569
15.00	9	52559	21	52602
20.00	9	52559	23	53750

Overlaps within a given range interval, J, are computed as follows:

Given: A_k , where k denotes the number of tracks, A, in an ARTS environment,

$$O_i = \left\{ \left(R(A_i) - 1.65 \right) \leq N \leq \left(R(A_i) + 1.65 \right) \right\} ; \quad i = 2, k; R(A_i) \leq J$$

where N represents number of aircraft whose range falls within the overlap interval i.

$O_i = N-1$ since the aircraft for which the overlaps are computed is not counted.

$R(A_i)$ stands for Range of track A_i .

Therefore, maximum overlaps within given interval J (denoted MAXJ) is defined as follows:

$$\text{MAXJ} = \text{MAX}(O_1, O_2, \dots, O_h)$$

For example, suppose A_2, A_3, A_4, A_5 are BCAS tracks with range of 1.67, 2.47, 3.43, 5.19 nmi away from BCAS Equipped Aircraft (A_1).

Then to compute the Maximum Number of Overlaps within a given range interval (5 nmi) do as follows:

1. First count number of aircraft within overlap interval of A_2 . Clearly, $R(A_2)$ and $R(A_3)$ falls within overlap interval of A_2 since:

$$\{1.67 - 1.65 \leq R(A_2) \leq 1.67 + 1.65\} \text{ and} \\ \{1.67 - 1.65 \leq R(A_3) \leq 1.67 + 1.65\} \text{ and } R(A_2) \leq 5 \text{ nmi}$$

So there are two aircraft within overlap interval of A_2 .

$$\therefore N = 2$$

$O_2 = N - 1 = 1$ since the aircraft A_2 for which the overlaps are computed is not counted.

2. Now count the number of aircraft within overlap interval of A_3 .

Clearly, $R(A_2)$, $R(A_3)$, $R(A_4)$ falls within overlap interval of A_3 and $R(A_3) \leq 5$ nmi.

$$\therefore N = 3$$

$O_3 = N - 1 = 2$ OVERLAPS since the aircraft A_3 for which the overlaps are computed is not counted.

3. Count number of aircraft within overlap interval of A_4 .

Clearly, $R(A_2)$, $R(A_3)$, $R(A_4)$ falls within overlap interval of A_4 and $R(A_4) \leq 5$ nmi.

$$\therefore N = 3 \text{ aircraft}$$

$O_4 = N - 1 = 2$ OVERLAPS since the aircraft A_4 for which overlaps are computed is not counted.

4. Since $R(A_5) > 5$ nmi, its overlaps are not considered.

Therefore, $\text{MAX}(0_2, 0_3, 0_4) = \text{MAX}(1, 2, 2) = 2$ Overlaps.

So the maximum number of overlaps within 5 nmi is 2.

ARTS Association vs. the Number of Overlapping Replies is shown in Figure A-13 for the Basic mode; Figure A-14 is for Whisper-shout. ARTS tracks are listed as being associated with BCAS tracks or unassociated, as the case may be. The resulting histograms are shown.

Overlaps of ARTS traffic versus percent associations can be defined as follows:

$$R_{\text{OVP}} = \sum_{\text{VP}=0}^{12} A_{\text{OVP}} / (A_{\text{OVP}} + M_{\text{OVP}} + 0.01) * 100$$

where A_{OVP} is the total number of associated ARTS tracks with OVP overlaps and

M_{OVP} is the total number of unassociated ARTS tracks with OVP overlaps. $(A_{\text{OVP}} + M_{\text{OVP}})$ represents total ARTS tracks with OVP overlaps.

This data has been truncated so as to include only those tracks within 10 nmi and above 15 degrees depression angle.

ARTS association vs. density of aircraft is given in the next set of data, Figures A-15 and A-16. The data truncation beyond 10 nmi and below 15 degrees depression angle applies here. We define density here as the number of established ARTS tracks within 10 nmi of the BCAS aircraft. Therefore a "density" of 31

aircraft corresponds to 0.1 aircraft per nmi². The percent association is determined by evaluating the fraction

$$A_K = NA_K / (NA_K + M_K)$$

where NA_K = number of associations in a density of K aircraft.

M_K = number of missed association in a density of K aircraft.

BCAS track correlation vs. overlaps is shown, for associated BCAS tracks, in Figures A-17 and A-18. Correlation describes the status of the BCAS track at every scan interval (about 4.7 seconds). If the BCAS track does not correlate with a BCAS report at that time, the track is tagged with a coast status flag. Correlation is therefore the fraction of time that a track is not in coast status. ARTS data is used to determine how many overlapping replies exist for each BCAS track sample. The data is truncated at 10 nmi and 15 degrees.

BCAS track correlation vs. density relates BCAS coasting to the density of aircraft within 10 nmi. Figures A-19 and A-20 shows this data, for the Basic and the Whisper-shout systems, respectively.

BCAS Consecutive coast characteristics for associated tracks are shown in Figure A-21.

This consecutive coast status is obtained directly from the BCAS data tapes with the 1-second interrogation rate.

Association performance as a function of the range and overlaps is presented in Figure A-22. The data is truncated at 10 nmi and 15 degrees depression angle.

Association performance as a function of the density and overlaps
is presented in Figure A-23. Here, too, the data is truncated
as noted.

RELATIVE ALTITUDE (FEET)	BASIC MODE																			
	41	25	29	42	58	57	69	36	39	39	28	39	39	39	39	39	39	39	39	39
10000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-2500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-3000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-3500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-4500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-5500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-6000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-6500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-7000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-7500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-8000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-8500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-9000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-9500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-10000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

FIGURE A-3
TOTAL BCAS ASSOCIATED AIRCRAFT TRACK MATRIX (R VS Z)

BASIC MODE																				RELATIVE RANGE (NMI)																				
																				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
CLOSING	-600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-570	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-540	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-510	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-480	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-450	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-420	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-390	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-360	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-330	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
RANGE RATE	-300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	-30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
SEPARATING	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
	300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0															
=====																				51	169	290	334	366	548	519	449	606	586	712	660	594	579	518	586	553	445	307	314	=====
-----																				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	-----

FIGURE A-4
TOTAL BCAS ASSOCIATED AIRCRAFT TRACK MATRIX (R VS R)

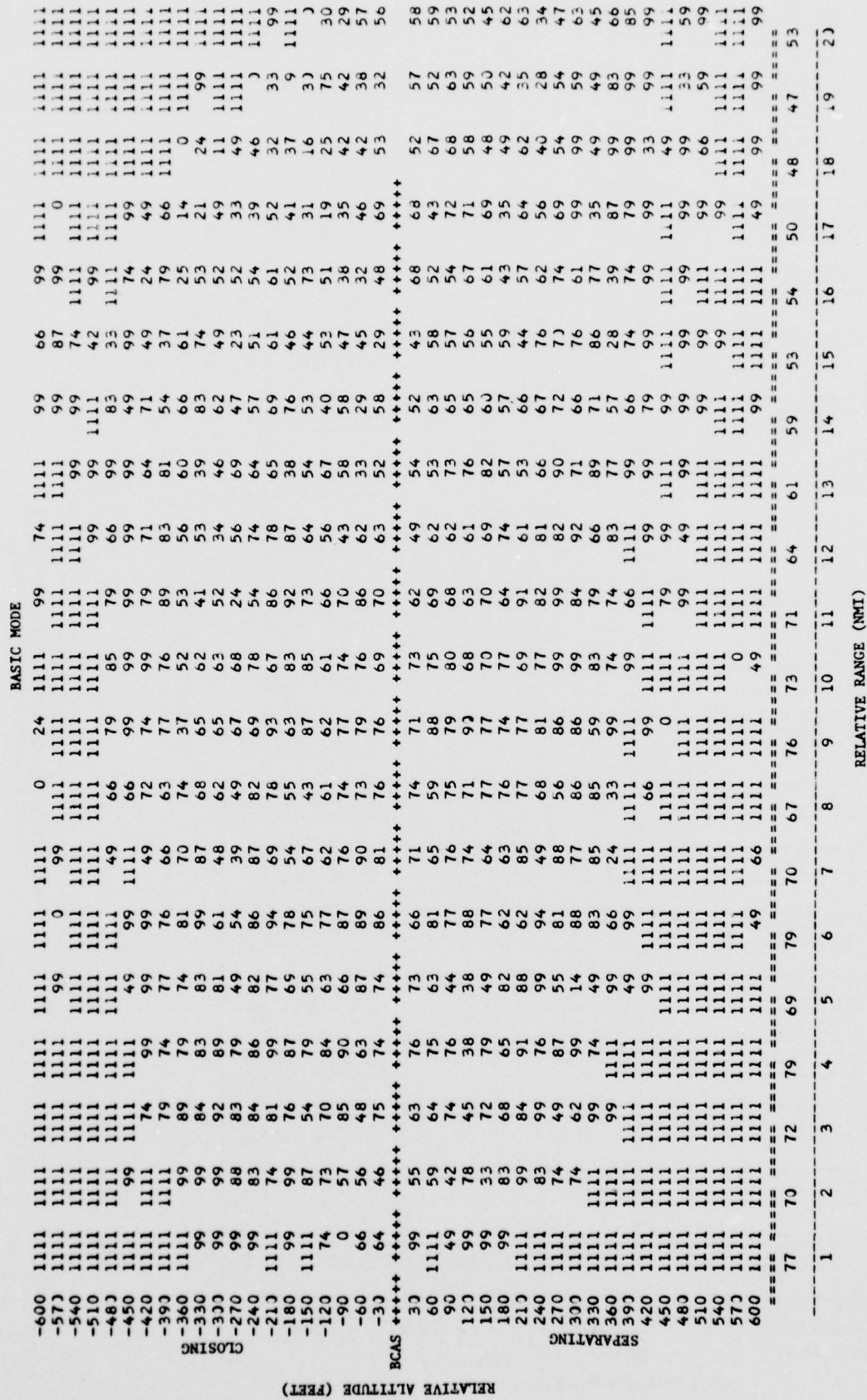


FIGURE A-6
RATIO OF BCAS ASSOCIATED AIRCRAFT TRACKS TO
TOTAL AIRCRAFT TRACKS (R VS R)

RANGE	TOTAL	ASSOC.	ZA
1	66	51	77
2	240	169	76
3	400	290	72
4	422	334	79
5	528	366	69
6	686	548	79
7	740	519	70
8	663	449	67
9	792	606	76
10	796	586	73
11	992	712	71
12	1019	660	64
13	964	594	61
14	969	579	59
15	974	518	53
16	1075	586	54
17	1086	553	50
18	913	445	48
19	646	307	47
20	586	314	53

FIGURE A-7
AIRCRAFT ASSOCIATION, FOR EACH MILE, FOR ALL ALTITUDES

a) RELATIVE ALT GREATER THAN 5K FT				b) RELATIVE ALT LESS THAN 5K FT			
RANGE	TOTAL	ASSOC.	%A	RANGE	TOTAL	ASSOC.	%A
1	0	0	0.	1	35	34	97.
2	0	0	0.	2	51	49	96.
3	8	8	100.	3	57	57	100.
4	22	19	86.	4	56	56	100.
5	22	18	82.	5	71	65	92.
6	44	38	86.	6	94	90	96.
7	37	27	73.	7	115	106	92.
8	23	18	78.	8	111	102	92.
9	69	62	90.	9	117	105	90.
10	65	53	82.	10	140	114	81.
11	54	35	65.	11	157	121	77.
12	56	51	91.	12	154	113	73.
13	63	59	94.	13	191	126	66.
14	97	83	86.	14	176	102	58.
15	112	93	83.	15	142	76	54.
16	110	100	91.	16	125	52	42.
17	111	63	57.	17	140	48	34.
18	116	69	59.	18	98	41	42.
19	91	67	74.	19	75	37	49.
20	63	55	87.	20	76	42	55.

FIGURE A-8
AIRCRAFT ASSOCIATION, EACH MILE, FOR VARIOUS ALTITUDE ZONES

c) RELATIVE ALT GREATER THAN -5K FT				d) RELATIVE ALT LESS THAN -5K FT			
RANGE	TOTAL	ASSOC.	%A	RANGE	TOTAL	ASSOC.	%A
1	28	15	54.	1	3	3	100.
2	89	66	74.	2	100	54	54.
3	139	102	73.	3	196	123	63.
4	173	140	81.	4	171	120	70.
5	203	129	64.	5	232	154	66.
6	257	214	83.	6	291	206	71.
7	279	177	63.	7	309	209	68.
8	276	168	61.	8	253	161	64.
9	236	165	70.	9	370	274	74.
10	281	182	65.	10	310	235	76.
11	339	221	65.	11	442	334	76.
12	363	196	54.	12	446	301	67.
13	345	157	46.	13	365	251	69.
14	376	181	48.	14	320	213	67.
15	427	191	45.	15	293	158	54.
16	507	256	50.	16	333	177	53.
17	409	164	40.	17	426	280	66.
18	386	137	35.	18	313	196	63.
19	249	122	49.	19	231	81	35.
20	280	129	46.	20	167	91	54.

FIGURE A-8
AIRCRAFT ASSOCIATION, EACH MILE, FOR VARIOUS ALTITUDE ZONES (CONTINUED)

> 5K FT ABOVE	IR	(0-5)	(6-10)	(11-15)	(16-20)
	TT	52	238	382	491
	IA	45	198	321	354
	IG	86.5	85.2	84.0	72.1
0 TO 5K FT ABOVE	IR	(0-5)	(6-10)	(11-15)	(16-20)
	TT	270	577	820	514
	IA	261	517	538	220
	IG	96.7	85.6	65.6	42.8
0 TO 5K FT BELOW	IR	(0-5)	(6-10)	(11-15)	(16-20)
	TT	632	1329	1850	1831
	IA	452	906	946	808
	IG	71.5	68.2	51.1	44.1
> 5K FT BELOW	IR	(0-5)	(6-10)	(11-15)	(16-20)
	TT	702	1533	1666	1470
	IA	454	1085	1257	825
	IG	64.7	73.8	67.4	56.1

FIGURE A-9
BCAS PERFORMANCE FOR VARIOUS ALTITUDE AND RANGE ZONES

RANGE	TOTAL	ASSOC.	%A
1	66	51	77.3
2	306	220	71.9
3	736	510	72.2
4	1128	844	74.8
5	1656	1210	73.1
6	2342	1758	75.1
7	3082	2277	73.9
8	3745	2726	72.8
9	4537	3332	73.4
10	5333	3918	73.5
11	6325	4630	73.2
12	7344	5290	72.0
13	8308	5884	70.8
14	9277	6463	69.7
15	10251	6981	68.1
16	11326	7567	66.8
17	12412	8120	65.4
18	13325	8565	64.3
19	13971	8872	63.5
20	14557	9186	63.1

FIGURE A-10
CUMULATIVE PERCENT OF AIRCRAFT ASSOCIATION

-600	.0010	.0041	.0021	.0021	.0010	.0021	.0000	.0000	.0010	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-570	.0000	.0021	.0010	.0000	.0000	.0000	.0000	.0000	.0010	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-540	.0000	.0010	.0021	.0000	.0000	.0010	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-510	.0000	.0000	.0010	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-480	.0010	.0010	.0021	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-450	.0000	.0000	.0021	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-420	.0000	.0010	.0041	.0000	.0000	.0021	.0021	.0021	.0010	.0010	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-390	.0021	.0000	.0021	.0000	.0031	.0021	.0021	.0021	.0010	.0010	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-360	.0000	.0031	.0021	.0021	.0041	.0052	.0021	.0021	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-330	.0000	.0021	.0031	.0031	.0041	.0052	.0021	.0031	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-300	.0000	.0010	.0062	.0052	.0021	.0031	.0021	.0000	.0010	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-270	.0041	.0031	.0031	.0041	.0052	.0021	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
-240	.0000	.0000	.0052	.0103	.0041	.0010	.0041	.0010	.0031	.0031	.0031	.0031	.0031	.0031	.0031	.0031	.0031	.0031	.0031	.0031	.0031
-210	.0000	.0031	.0062	.0103	.0041	.0031	.0072	.0000	.0021	.0021	.0021	.0021	.0021	.0021	.0021	.0021	.0021	.0021	.0021	.0021	.0021
-180	.0000	.0031	.0072	.0021	.0021	.0021	.0041	.0082	.0113	.0031	.0031	.0082	.0021	.0010	.0031	.0000	.0010	.0000	.0000	.0000	.0000
-150	.0000	.0021	.0021	.0010	.0031	.0052	.0021	.0041	.0031	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010
-120	.0000	.0031	.0103	.0124	.0124	.0113	.0134	.0134	.0134	.0134	.0134	.0134	.0134	.0134	.0134	.0134	.0134	.0134	.0134	.0134	.0134
-90	.0010	.0010	.0072	.0000	.0155	.0052	.0010	.0041	.0062	.0041	.0062	.0072	.0021	.0031	.0021	.0021	.0031	.0010	.0021	.0062	.0000
-60	.0000	.0000	.0000	.0072	.0082	.0041	.0041	.0072	.0113	.0062	.0041	.0093	.0113	.0093	.0113	.0093	.0113	.0093	.0113	.0093	.0113
-30	.0000	.0021	.0031	.0031	.0052	.0062	.0052	.0072	.0082	.0186	.0062	.0144	.0031	.0031	.0062	.0052	.0000	.0052	.0021	.0041	.0041
30	.0010	.0000	.0010	.0010	.0021	.0062	.0062	.0052	.0113	.0062	.0062	.0062	.0062	.0062	.0062	.0062	.0062	.0062	.0062	.0062	.0062
60	.0010	.0000	.0021	.0021	.0041	.0041	.0124	.0124	.0124	.0124	.0124	.0124	.0124	.0124	.0124	.0124	.0124	.0124	.0124	.0124	.0124
90	.0000	.0000	.0010	.0041	.0093	.0041	.0041	.0103	.0082	.0062	.0041	.0031	.0031	.0031	.0031	.0031	.0031	.0031	.0031	.0031	.0031
120	.0000	.0021	.0021	.0062	.0031	.0010	.0052	.0113	.0062	.0082	.0062	.0062	.0062	.0062	.0062	.0062	.0062	.0062	.0062	.0062	.0062
150	.0000	.0010	.0021	.0041	.0134	.0062	.0052	.0175	.0082	.0134	.0144	.0072	.0052	.0052	.0103	.0103	.0062	.0062	.0062	.0062	.0062
180	.0000	.0000	.0000	.0052	.0062	.0021	.0093	.0093	.0082	.0103	.0082	.0052	.0052	.0052	.0072	.0072	.0021	.0052	.0031	.0041	.0041
210	.0010	.0021	.0010	.0031	.0021	.0021	.0052	.0052	.0052	.0062	.0062	.0062	.0062	.0062	.0062	.0062	.0062	.0062	.0062	.0062	.0062
240	.0000	.0000	.0021	.0021	.0041	.0031	.0021	.0041	.0021	.0082	.0031	.0103	.0093	.0093	.0000	.0103	.0052	.0041	.0082	.0031	.0021
270	.0000	.0000	.0000	.0000	.0041	.0031	.0021	.0010	.0021	.0031	.0031	.0031	.0031	.0031	.0031	.0031	.0031	.0031	.0031	.0031	.0031
300	.0010	.0000	.0000	.0010	.0021	.0021	.0021	.0072	.0031	.0052	.0041	.0041	.0041	.0041	.0041	.0041	.0041	.0041	.0041	.0041	.0041
330	.0000	.0000	.0010	.0010	.0021	.0021	.0021	.0010	.0031	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
360	.0000	.0000	.0000	.0000	.0010	.0000	.0000	.0000	.0031	.0021	.0031	.0021	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
390	.0000	.0000	.0000	.0000	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010
420	.0010	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
450	.0000	.0000	.0000	.0000	.0021	.0000	.0000	.0010	.0000	.0010	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
480	.0000	.0000	.0010	.0021	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010
510	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
540	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
570	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
600	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
630	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
660	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
690	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
720	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
750	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
780	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
810	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
840	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
870	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
900	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
930	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
960	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
990	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
1020	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
1050	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
1080	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
1110	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
1140	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
1170	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
1200	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
1230	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
1260	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000									

FIGURE A-12
PROBABILITY OF PHANTOM OCCURRENCES (R VS R)

OVERLAPS	0	+++++	655
	1	+++++	728
	2	+++++	750
	3	+++++	560
	4	+++++	284
	5	+++++	134
	6	+++++	73
	7	++++	34
	8	++++	15
	9	++++	0
	10	++++	0
	11	++++	0
	12	++++	0

a) NUMBER OF SUCCESSFUL ASSOCIATIONS

OVERLAPS	0	+++++	237
	1	+++++	307
	2	+++++	354
	3	+++++	251
	4	+++++	128
	5	+++++	58
	6	+++++	44
	7	++++	16
	8	++++	5
	9	++++	3
	10	++++	0
	11	++++	0
	12	++++	0

b) NUMBER OF MISSED ASSOCIATIONS

OVERLAPS	0	+++++	73
	1	+++++	70
	2	+++++	68
	3	+++++	69
	4	+++++	69
	5	+++++	70
	6	+++++	62
	7	+++++	68
	8	+++++	75
	9	++++	0
	10	++++	1111
	11	++++	1111
	12	++++	1111

c) PERCENT ASSOCIATION

NOTE: DATA TRUNCATED AT 10 NMT
AND 15° DEPRESSION ANGLE

FIGURE A-13
ARTS ASSOCIATION VS. OVERLAPS (BASIC)

OVERLAPS	0	671
	1	780
	2	824
	3	667
	4	344
	5	171
	6	98
	7	47
	8	9
	9	1
	10	0
	11	0
	12	0

a) NUMBER OF SUCCESSFUL ASSOCIATIONS

OVERLAPS	0	206
	1	277
	2	281
	3	187
	4	67
	5	48
	6	31
	7	19
	8	11
	9	3
	10	0
	11	0
	12	0

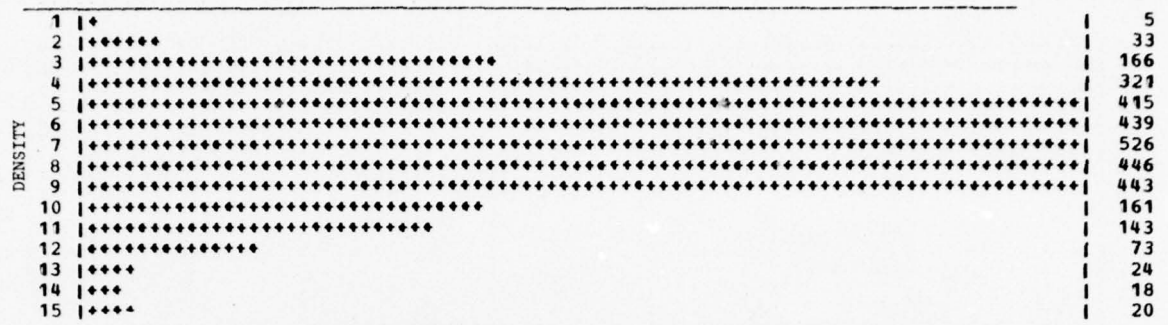
b) NUMBER OF MISSED ASSOCIATIONS

OVERLAPS	0	76
	1	74
	2	74
	3	78
	4	84
	5	78
	6	76
	7	71
	8	45
	9	25
	10	1111
	11	1111
	12	1111

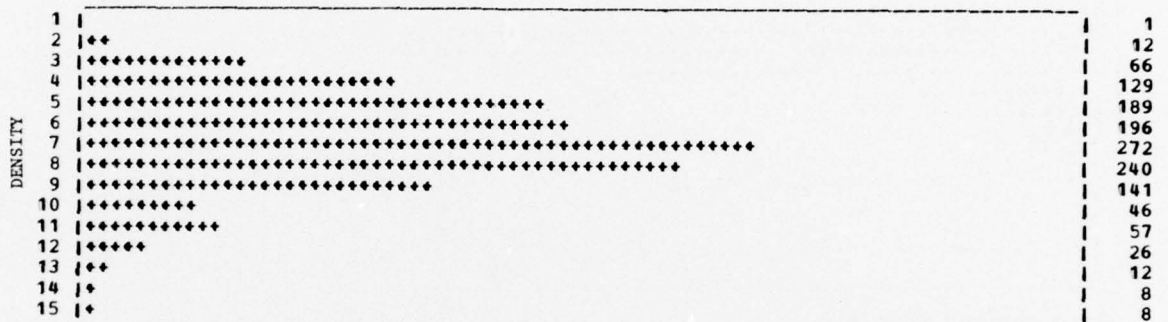
c) PERCENT ASSOCIATION

NOTE: DATA TRUNCATED AT 10 NMI
AND 15° DEPRESSION ANGLE

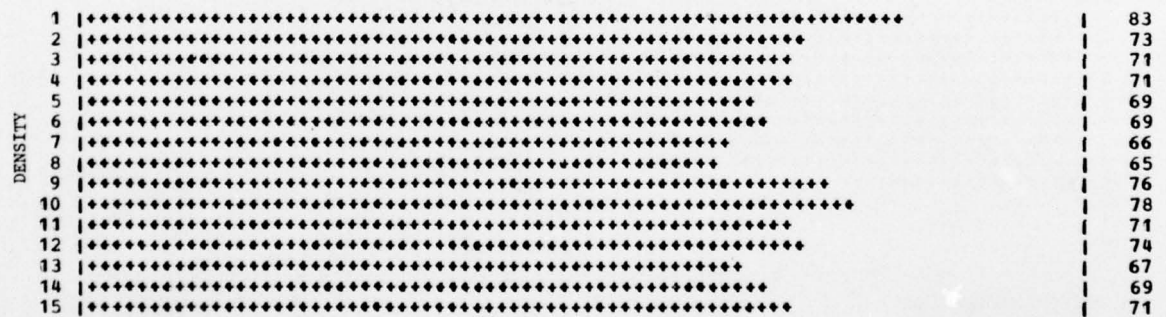
FIGURE A-14
ARTS ASSOCIATION VS. OVERLAPS (WHISPER-SHOUT)



a) NUMBER OF SUCCESSFUL ASSOCIATIONS



b) NUMBER OF MISSED ASSOCIATIONS

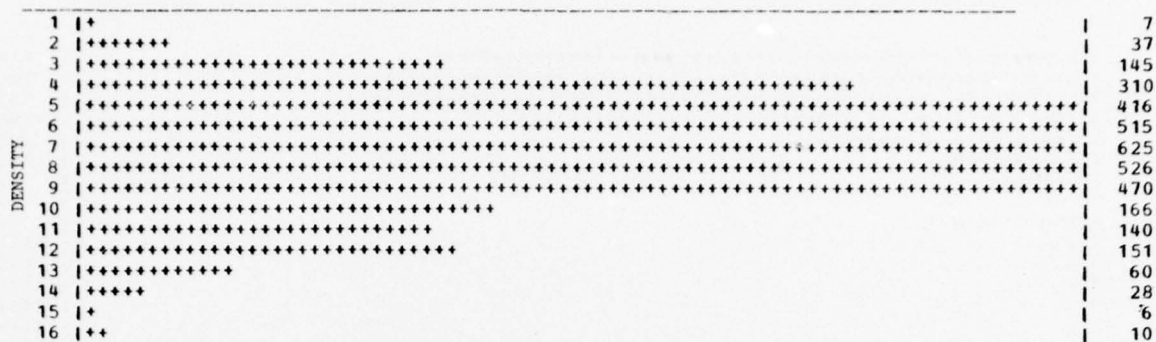


c) PERCENT ASSOCIATION

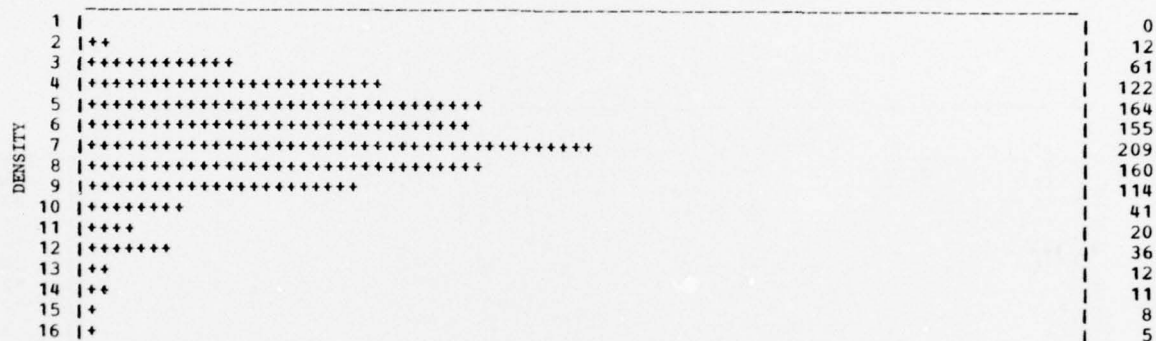
NOTE: 1. DATA TRUNCATED AT 10 NMI
AND 15° DEPRESSION ANGLE

2. DENSITY = THE NUMBER OF
AIRCRAFT WITHIN 10 NMI

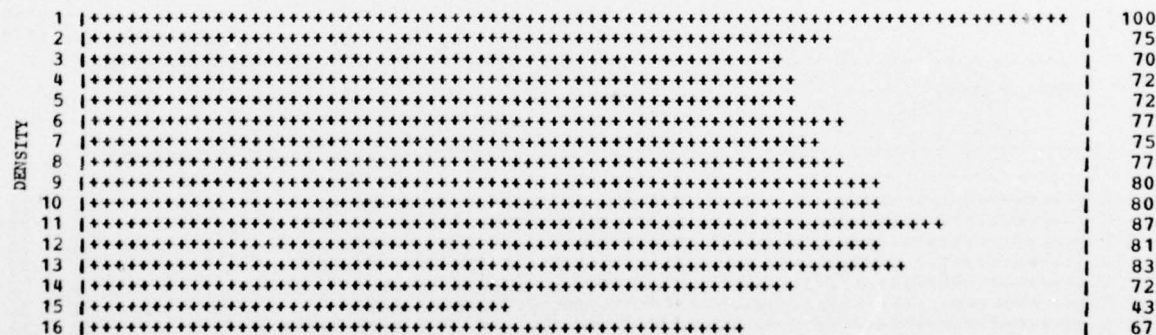
FIGURE A-15
ARTS ASSOCIATION VS. AIRCRAFT DENSITY (BASIC)



a) NUMBER OF SUCCESSFUL ASSOCIATIONS



b) NUMBER OF MISSED ASSOCIATIONS



c) PERCENT ASSOCIATION

NOTE: 1. DATA TRUNCATED AT 10 NMI
AND 15° DEPRESSION ANGLE

2. DENSITY = THE NUMBER OF
AIRCRAFT WITHIN 10 NMI

FIGURE A-16
ARTS ASSOCIATION VS. AIRCRAFT DENSITY (WHISPER-SHOUT)

OVERLAPS	0	*****	514
	1	*****	566
	2	*****	587
	3	*****	446
	4	*****	207
	5	*****	100
	6	*****	61
	7	*****	22
	8	*****	12
	9		1111
	10		1111
	11		1111
	12		1111
	13		1111
	14		1111
	15		1111
	16		1111

a) NUMBER OF SUCCESSFUL CORRELATIONS

OVERLAPS	0	*****	141
	1	*****	162
	2	*****	163
	3	*****	114
	4	*****	77
	5	*****	34
	6	*****	12
	7	*****	12
	8		3
	9		1111
	10		1111
	11		1111
	12		1111
	13		1111
	14		1111
	15		1111
	16		1111

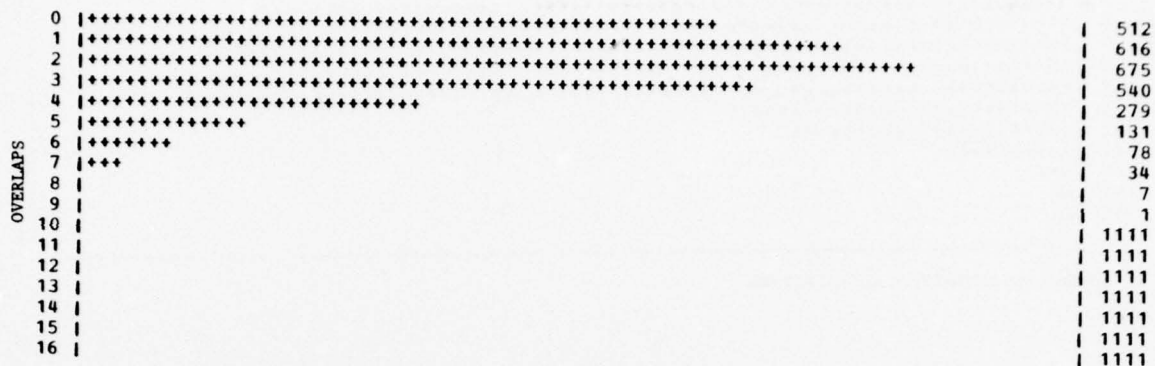
b) NUMBER OF COASTS

OVERLAPS	0	*****	78
	1	*****	78
	2	*****	78
	3	*****	79
	4	*****	73
	5	*****	75
	6	*****	83
	7	*****	65
	8	*****	80
	9		1111
	10		1111
	11		1111
	12		1111
	13		1111
	14		1111
	15		1111
	16		1111

c) PERCENT CORRELATION

NOTE: DATA TRUNCATED AT 10 NMI
AND 15° DEPRESSION ANGLE

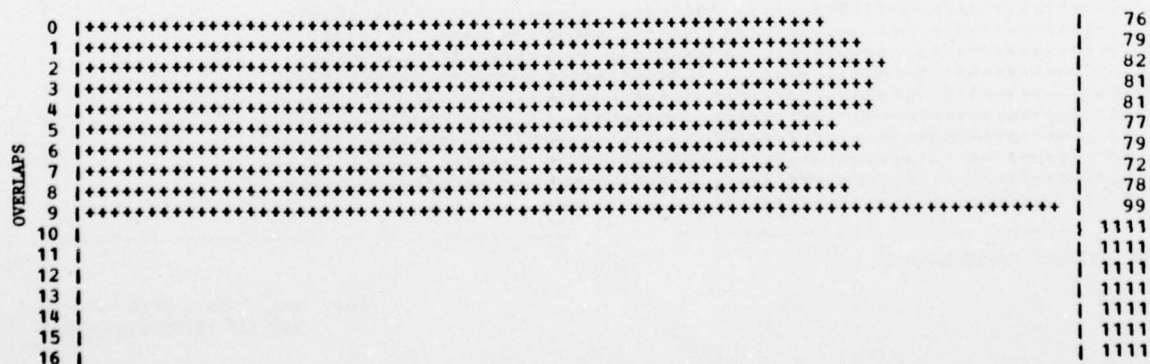
FIGURE A-17
BCAS TRACK CORRELATION VS. OVERLAPS (BASIC)



a) NUMBER OF SUCCESSFUL CORRELATIONS



b) NUMBER OF COASTS



c) PERCENT CORRELATION

DATA TRUNCATED AT 10 NMI
AND 15° DEPRESSION ANGLE

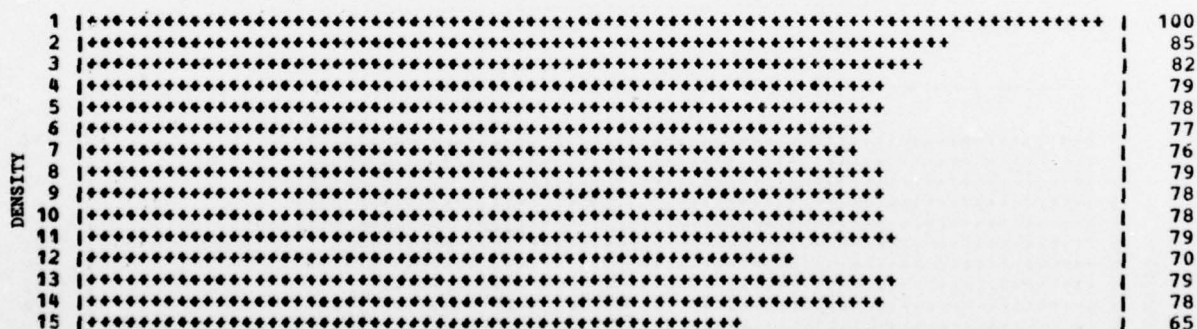
FIGURE A-18
BCAS TRACK CORRELATION VS. OVERLAPS (WHISPER-SHOUT)



a) NUMBER OF SUCCESSFUL CORRELATIONS



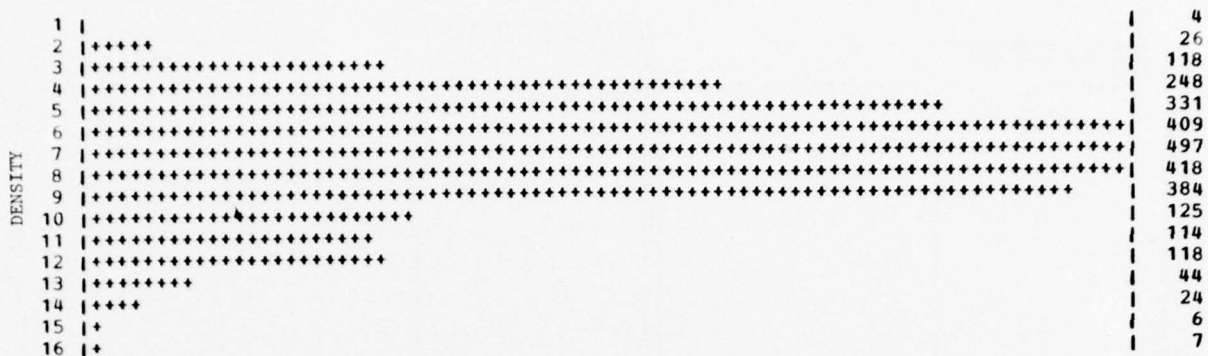
b) NUMBER OF COASTS



c) PERCENT CORRELATION

NOTE: DATA TRUNCATED AT 10 NMI
AND 15° DEPRESSION ANGLE

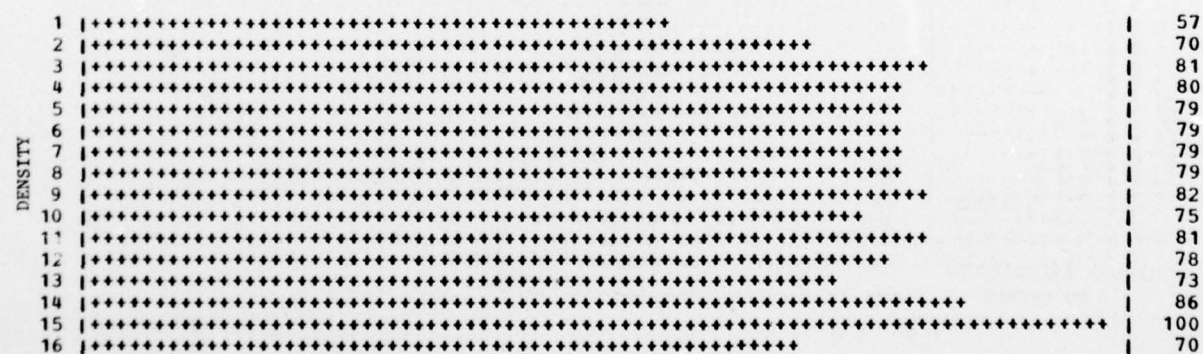
FIGURE A-19
BCAS TRACK CORRELATION VS. DENSITY (BASIC)



a) NUMBER OF SUCCESSFUL CORRELATIONS



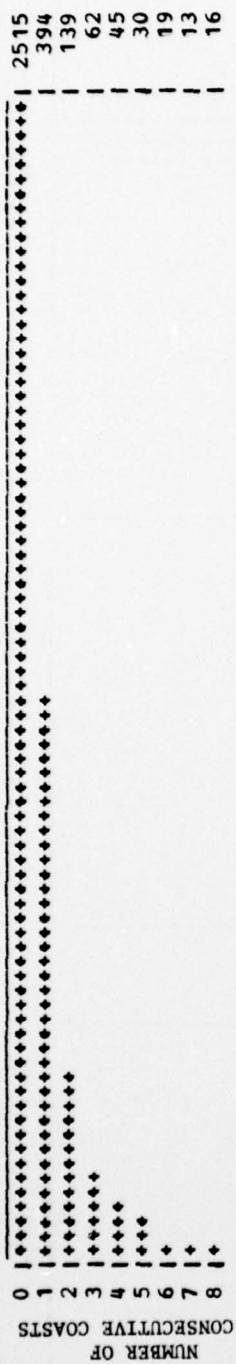
b) NUMBER OF COASTS



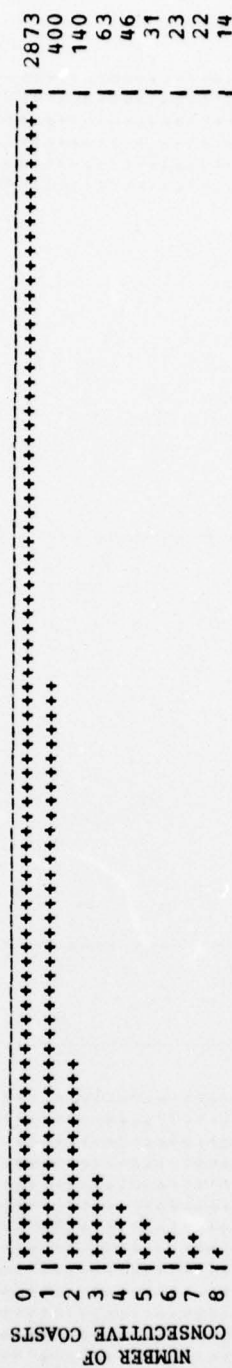
c) PERCENT CORRELATION

NOTE: DATA TRUNCATED AT 10 NMI
AND 15° DEPRESSION ANGLE

FIGURE A-20
BCAS TRACK CORRELATION VS. DENSITY (WHISPER-SHOUT)



a) BASIC



b) WHISPER-SHOUT

FIGURE A-21
BCAS CONSECUTIVE COAST STATUS FOR ASSOCIATED TRACKS

	SUCCESSFUL ASSOCIATIONS (BASIC)												RANGE
	1	2	3	4	5	6	7	8	9	10			
0	32	60	109	63	65	90	53	44	68	30			
1	6	35	68	98	102	74	90	67	100	88			
2	2	23	58	92	78	134	94	68	102	99			
3	18	5	49	36	50	91	116	96	64	83			
4	11	11	11	11	3	19	49	40	30	74	69		
5	11	11	11	11	1	4	16	12	17	24	60		
6	10	10	10	10	10	10	2	80	14	23	26		
7	11	11	11	11	11	11	11	11	1	5	15	13	
8	11	11	11	11	11	11	11	11	11	11	8	7	
9	11	11	11	11	11	11	11	11	11	11	11	11	
10	11	11	11	11	11	11	11	11	11	11	11	11	
11	11	11	11	11	11	11	11	11	11	11	11	11	
12	11	11	11	11	11	11	11	11	11	11	11	11	
OVERLAPS													

a) SUCCESSFUL ASSOCIATIONS (BASIC)

	SUCCESSFUL ASSOCIATIONS (BASIC)												RANGE
	1	2	3	4	5	6	7	8	9	10			
0	12	28	29	21	29	21	22	36	21	18			
1	2	17	48	32	47	42	31	30	26	39			
2	11	16	33	26	48	26	53	55	51	46			
3	11	5	7	6	30	30	69	43	29	32			
4	11	11	11	11	11	7	16	30	22	24	29		
5	11	11	11	11	11	11	1	9	43	24			
6	11	11	11	11	11	11	4	7	10	11	12		
7	11	11	11	11	11	11	2	3	4	7			
8	11	11	11	11	11	11	11	11	11	11	5		
9	11	11	11	11	11	11	11	11	11	11	3		
10	11	11	11	11	11	11	11	11	11	11	11		
11	11	11	11	11	11	11	11	11	11	11	11		
12	11	11	11	11	11	11	11	11	11	11	11		
OVERLAPS													

b) MISSED ASSOCIATIONS (BASIC)

	SUCCESSFUL ASSOCIATIONS (WHISPER-SHOUT)												RANGE
	1	2	3	4	5	6	7	8	9	10			
0	33	110	113	59	62	82	59	53	69	31			
1	7	39	77	106	112	84	86	77	100	92			
2	3	30	69	96	94	135	109	80	105	103			
3	11	3	27	47	79	106	140	107	73	85			
4	11	2	2	6	17	52	52	41	89	83			
5	11	11	11	1	1	15	18	26	32	78			
6	11	11	11	11	2	4	15	26	21	30			
7	11	11	11	11	1	3	5	12	13	13			
8	11	11	11	11	11	11	11	11	11	6	3		
9	11	11	11	11	11	11	11	11	11	1	11		
10	11	11	11	11	11	11	11	11	11	11	11		
11	11	11	11	11	11	11	11	11	11	11	11		
12	11	11	11	11	11	11	11	11	11	11	11		
OVERLAPS													

c) SUCCESSFUL ASSOCIATIONS (WHISPER-SHOUT)

	MISSED ASSOCIATIONS (WHISPER-SHOUT)												RANGE
	1	2	3	4	5	6	7	8	9	10			
0	11	19	25	19	22	26	18	28	18	20			
1	2	14	32	30	44	34	32	25	29	35			
2	11	16	25	15	30	34	36	45	41	39			
3	11	5	3	6	18	18	58	32	21	26			
4	11	11	1	11	3	12	12	15	12	12			
5	11	11	11	11	1	5	7	5	11	19			
6	11	11	11	11	11	2	5	3	11	10			
7	11	11	11	11	11	11	11	1	2	9	7		
8	11	11	11	11	11	11	11	11	11	2	9		
9	11	11	11	11	11	11	11	11	11	11	3		
10	11	11	11	11	11	11	11	11	11	11	11		
11	11	11	11	11	11	11	11	11	11	11	11		
12	11	11	11	11	11	11	11	11	11	11	11		
OVERLAPS													

d) MISSED ASSOCIATIONS (WHISPER-SHOUT)

NOTE: DATA TRUNCATED AT 10 NMI
AND 15° DEPRESSION ANGLE

FIGURE A-22
ASSOCIATION PERFORMANCE AS A FUNCTION OF RANGE AND OVERLAPS

DENSITY	0	1	2	3	4	5	6	7	8	9	10	11	12
1	3	1111	4	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111
2	36	1	1111	3	1111	1111	1111	1111	1111	1111	1111	1111	1111
3	107	34	3	1	1111	1111	1111	1111	1111	1111	1111	1111	1111
4	157	102	39	4	4	4	4	4	4	4	4	4	4
5	115	160	115	14	7	3	2	1111	1111	1111	1111	1111	1111
6	68	169	168	89	18	3	1111	1111	1111	1111	1111	1111	1111
7	86	181	177	147	37	33	8	2	1111	1111	1111	1111	1111
8	40	79	116	147	89	42	6	7	1111	1111	1111	1111	1111
9	29	54	115	133	84	33	18	4	1111	1111	1111	1111	1111
10	11	16	20	35	41	22	16	5	1111	1111	1111	1111	1111
11	7	3	37	35	22	6	22	6	1111	1111	1111	1111	1111
12	4	9	19	56	30	9	14	7	2	1	1111	1111	1111
13	4	7	6	7	8	10	8	9	1	1111	1111	1111	1111
14	1	5	4	3	1	4	4	5	1	1111	1111	1111	1111
15	1	1111	1	1	1111	1111	1111	1	2	1111	1111	1111	1111
16	2	1111	1111	1	3	1111	1111	1	3	1111	1111	1111	1111
	671	780	824	667	344	171	98	47	9	1	0	0	3612

c) SUCCESSFUL CORRELATIONS (WHISPER-SHOUT)

DENSITY	0	1	2	3	4	5	6	7	8	9	10	11	12
1	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111
2	12	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111
3	40	19	2	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111
4	63	32	19	4	3	1	1111	1111	1111	1111	1111	1111	1111
5	54	54	46	5	1	3	1	1111	1111	1111	1111	1111	1111
6	17	62	48	24	3	1	1111	1111	1111	1111	1111	1111	1111
7	11	57	63	55	4	10	3	2	1111	1111	1111	1111	1111
8	5	23	48	48	24	10	2	4	1111	1111	1111	1111	1111
9	4	21	33	27	17	3	6	3	1111	1111	1111	1111	1111
10	1111	5	3	12	6	8	5	2	1111	1111	1111	1111	1111
11	1111	1111	5	5	1	2	7	1111	1111	1111	1111	1111	1111
12	1111	3	7	8	2	5	6	5	1111	1111	1111	1111	1111
13	1111	1	4	1111	1	3	1	1	1111	1111	1111	1111	1111
14	1111	1111	3	1	1111	1	1	1	1111	1111	1111	1111	1111
15	1111	1111	1111	1	1	1	1	1	1111	1111	1111	1111	1111
16	1111	1111	1111	1	1	1	1	1	1111	1111	1111	1111	1111
	206	277	281	187	67	48	31	19	11	3	0	0	1130

d) MISSED CORRELATIONS (WHISPER-SHOUT)

DENSITY	0	1	2	3	4	5	6	7	8	9	10	11	12
1	2	1111	3	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111
2	32	1	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111
3	116	45	3	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111
4	162	110	38	4	3	1111	1111	1111	1111	1111	1111	1111	1111
5	118	152	117	21	4	2	1	1111	1111	1111	1111	1111	1111
6	59	149	142	69	14	3	1111	1111	1111	1111	1111	1111	1111
7	71	113	148	120	42	24	7	1	1111	1111	1111	1111	1111
8	44	67	105	120	69	30	7	4	1111	1111	1111	1111	1111
9	24	53	116	130	74	29	15	2	1111	1111	1111	1111	1111
10	6	13	32	44	35	25	5	1	1111	1111	1111	1111	1111
11	11	10	28	29	28	11	23	9	1	1111	1111	1111	1111
12	6	6	9	13	15	4	11	8	1	1111	1111	1111	1111
13	1	5	2	2	7	3	2	1	1	1111	1111	1111	1111
14	1111	4	3	1	1111	1111	2	5	3	1111	1111	1111	1111
15	3	1111	2	3	1111	1111	3	9	1111	1111	1111	1111	1111
	655	728	750	560	284	134	73	34	15	0	0	0	3233

a) SUCCESSFUL CORRELATIONS (BASIC)

DENSITY	0	1	2	3	4	5	6	7	8	9	10	11	12
1	1111	1111	1	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111
2	12	1111	1	1111	1111	1111	1111	1111	1111	1111	1111	1111	1111
3	43	17	5	1	1111	1111	1111	1111	1111	1111	1111	1111	1111
4	61	45	16	2	3	2	1111	1111	1111	1111	1111	1111	1111
5	60	59	57	6	3	2	2	1111	1111	1111	1111	1111	1111
6	25	75	51	41	3	4	1111	1111	1111	1111	1111	1111	1111
7	22	58	69	75	26	15	5	2	1111	1111	1111	1111	1111
8	11	29	72	55	47	15	4	7	1111	1111	1111	1111	1111
9	3	12	46	38	25	9	8	3	1111	1111	1111	1111	1111
10	1111	6	11	14	8	3	4	1111	1111	1111	1111	1111	1111
11	1111	2	11	11	5	8	18	2	1111	1111	1111	1111	1111
12	1111	3	8	3	4	4	3	1	1111	1111	1111	1111	1111
13	1111	1	3	3	3	1	1111	1111	1111	1111	1111	1111	1111
14	1111	1111	3	1	1111	1111	1	2	1	1111	1111	1111	1111
15	1111	1111	1	1	1	1	1	2	2	1111	1111	1111	1111
	237	307	354	251	128	58	44	16	5	3	0	0	1403

b) MISSED CORRELATIONS (BASIC)

NOTE: DATA TRUNCATED AT 10 NMI
AND 15° DEPRESSION ANGLE

FIGURE A-23
ASSOCIATION PERFORMANCE AS A FUNCTION OF DENSITY AND OVERLAPS

APPENDIX B

DATA COLLECTED IN NAFEC TESTS TO DETERMINE COVERAGE

When the influence of aircraft antenna coverage was being investigated a flight test in the vicinity of NAFEC was instigated. Intersections over the Waterloo VOR were run with the target aircraft flying at various altitudes above and below the BCAS aircraft. The test is described in Section 6.2.3; the data is graphically presented here in Figures B-1 through B-32.

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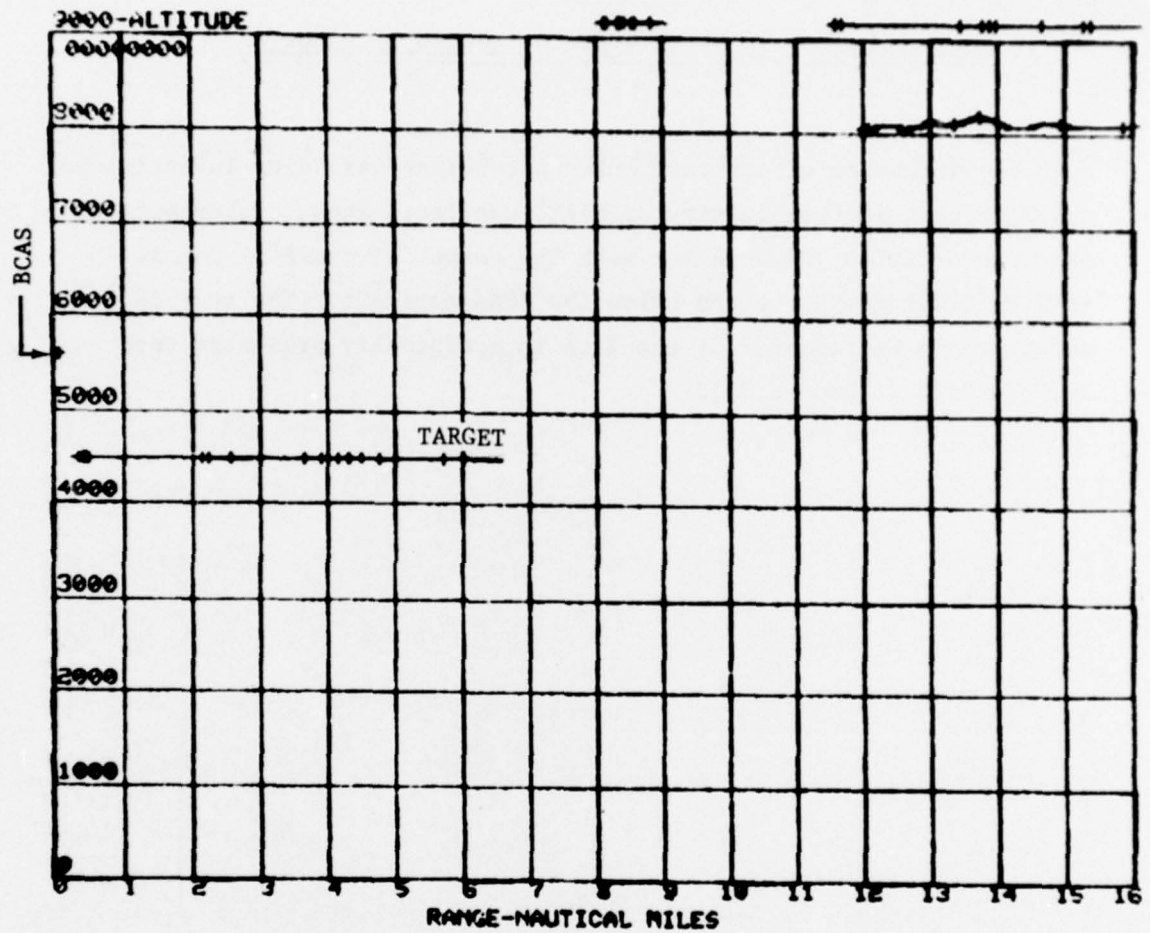


FIGURE B-1
INBOUND HEAD-ON ENCOUNTER (-1000 FT.)

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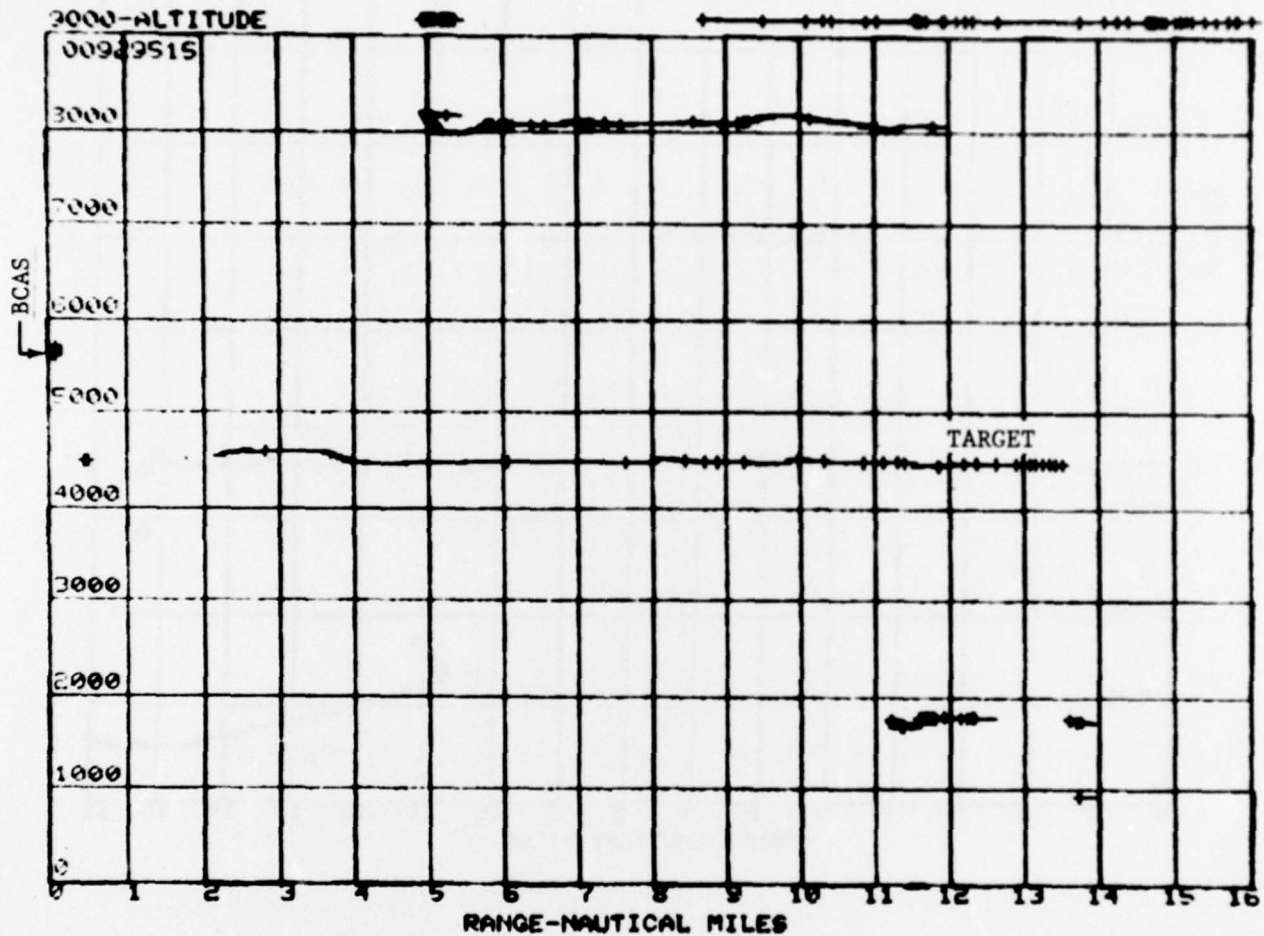


FIGURE B-2
OUTBOUND HEAD-ON ENCOUNTER (-1000 FT.)

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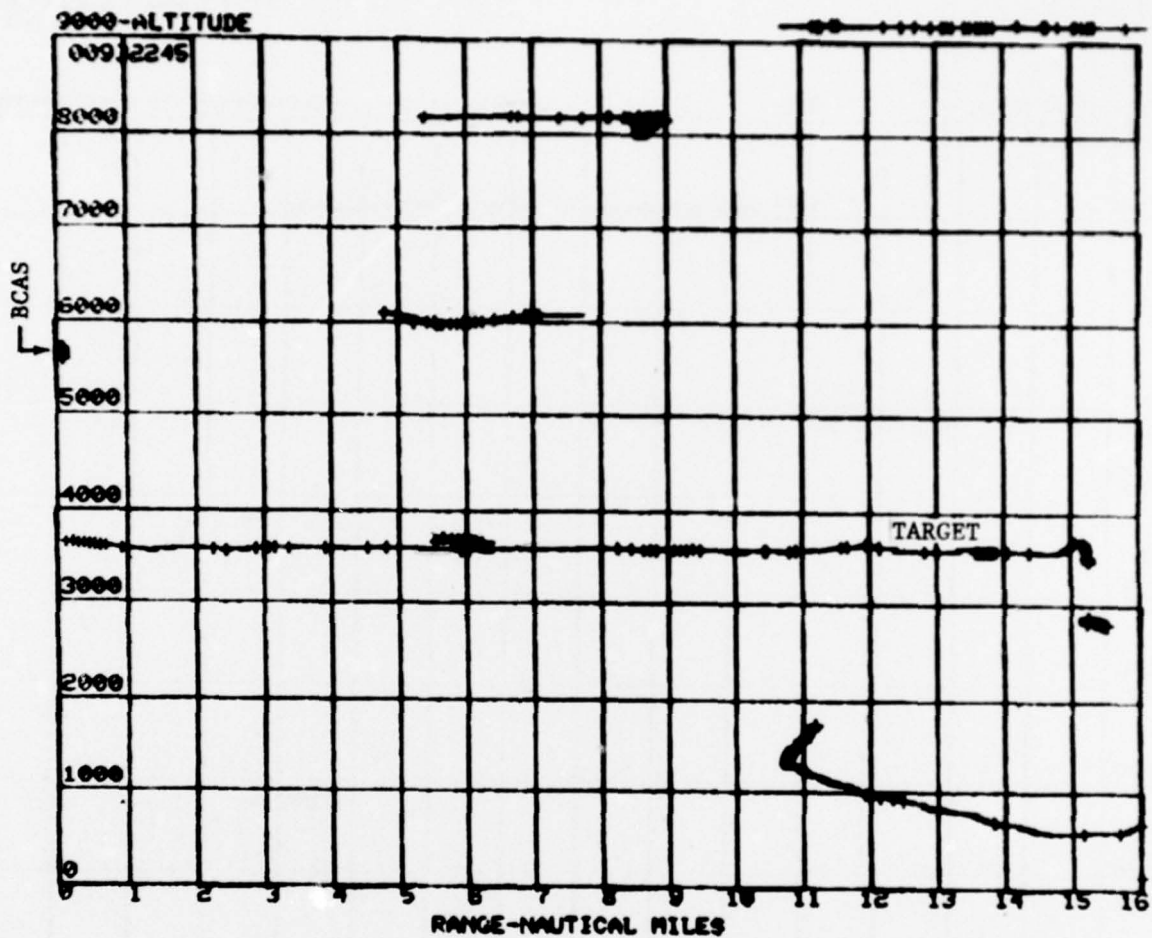


FIGURE B-3
INBOUND HEAD-ON ENCOUNTER (-2000 FT.)

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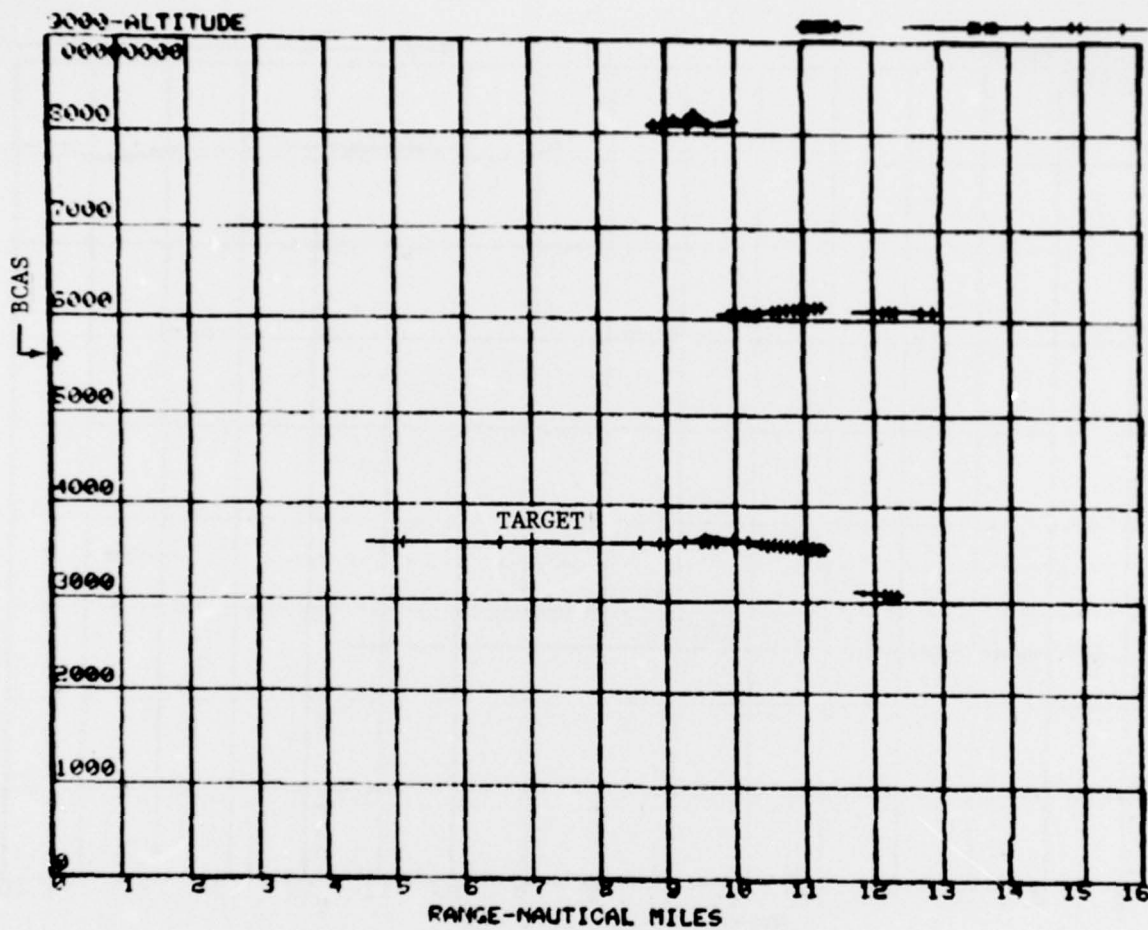


FIGURE B-4
OUTBOUND HEAD-ON ENCOUNTER (-2000 FT.)

BEST AVAILABLE COPY

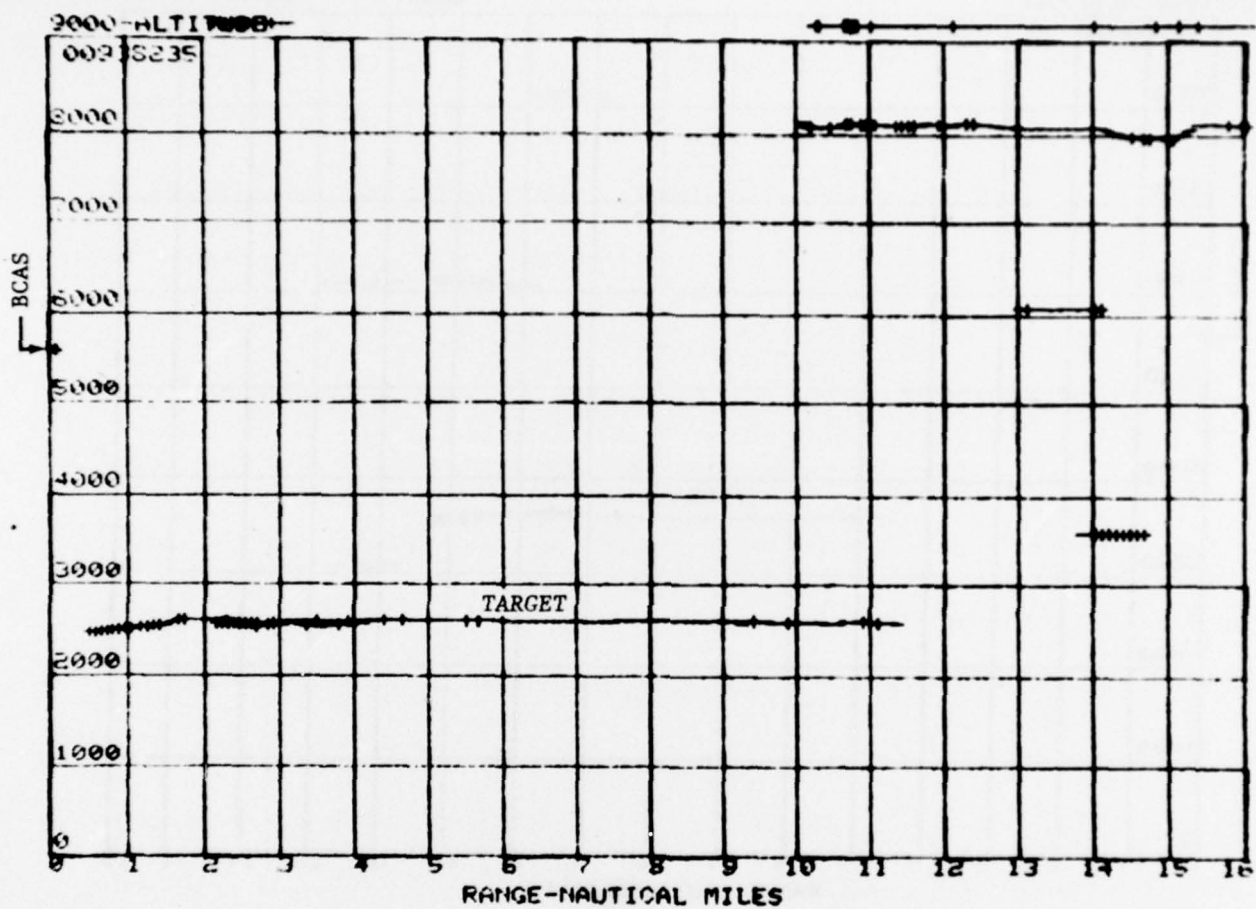


FIGURE B-5
INBOUND HEAD-ON ENCOUNTER (-3000 FT.)

BEST AVAILABLE COPY

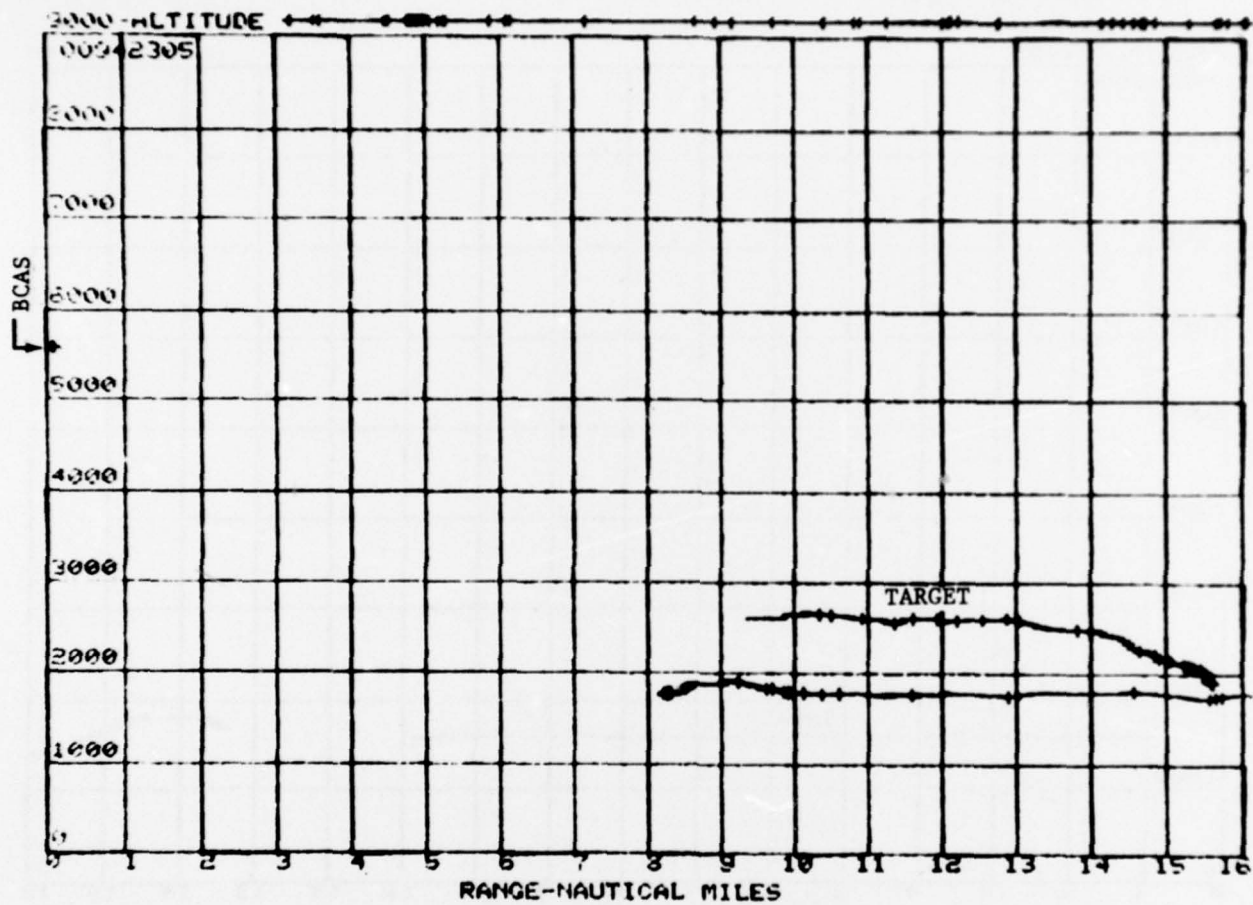


FIGURE B-6
OUTBOUND HEAD-ON ENCOUNTER (-3000 FT.)

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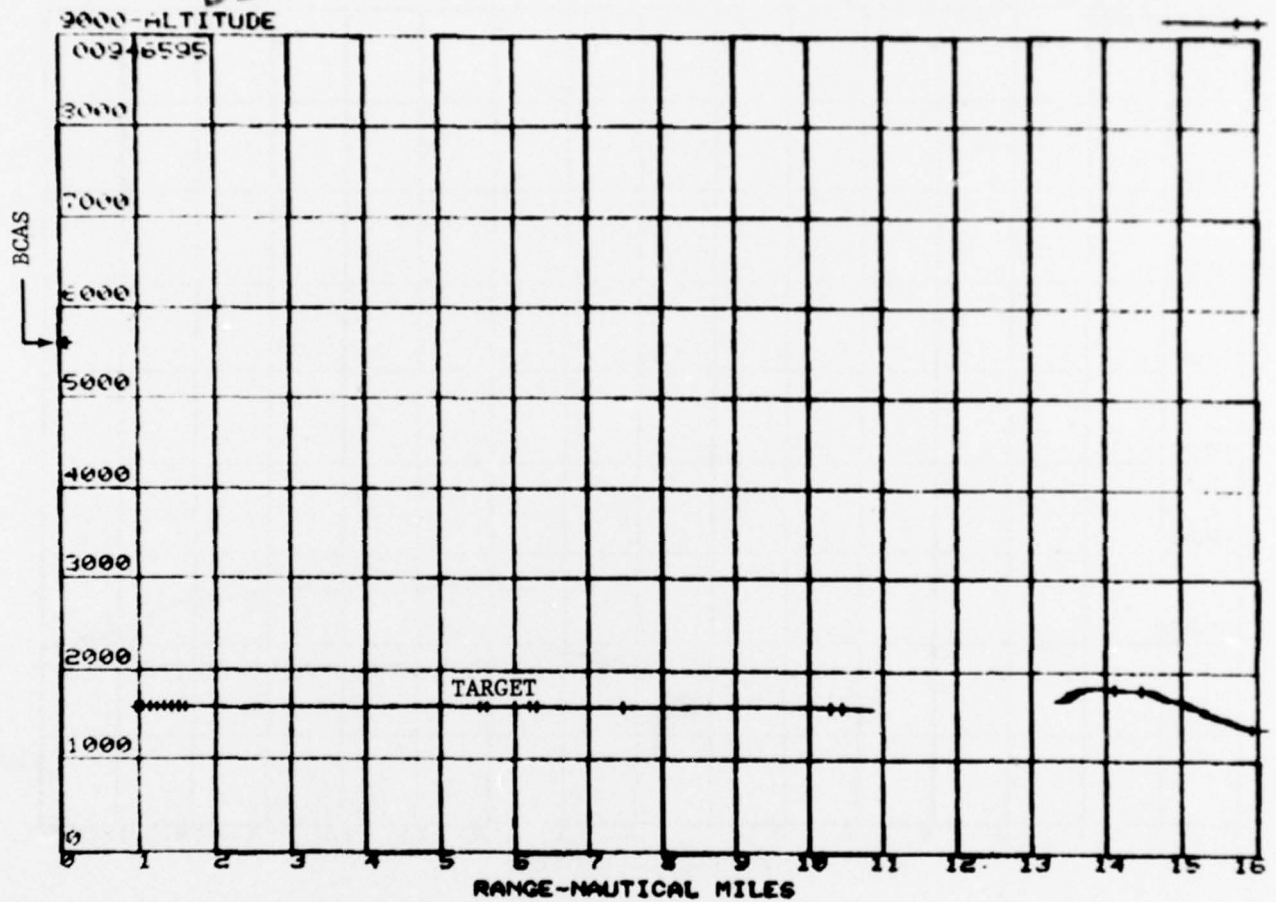


FIGURE B-7
INBOUND HEAD-ON ENCOUNTER (-4000 FT.)

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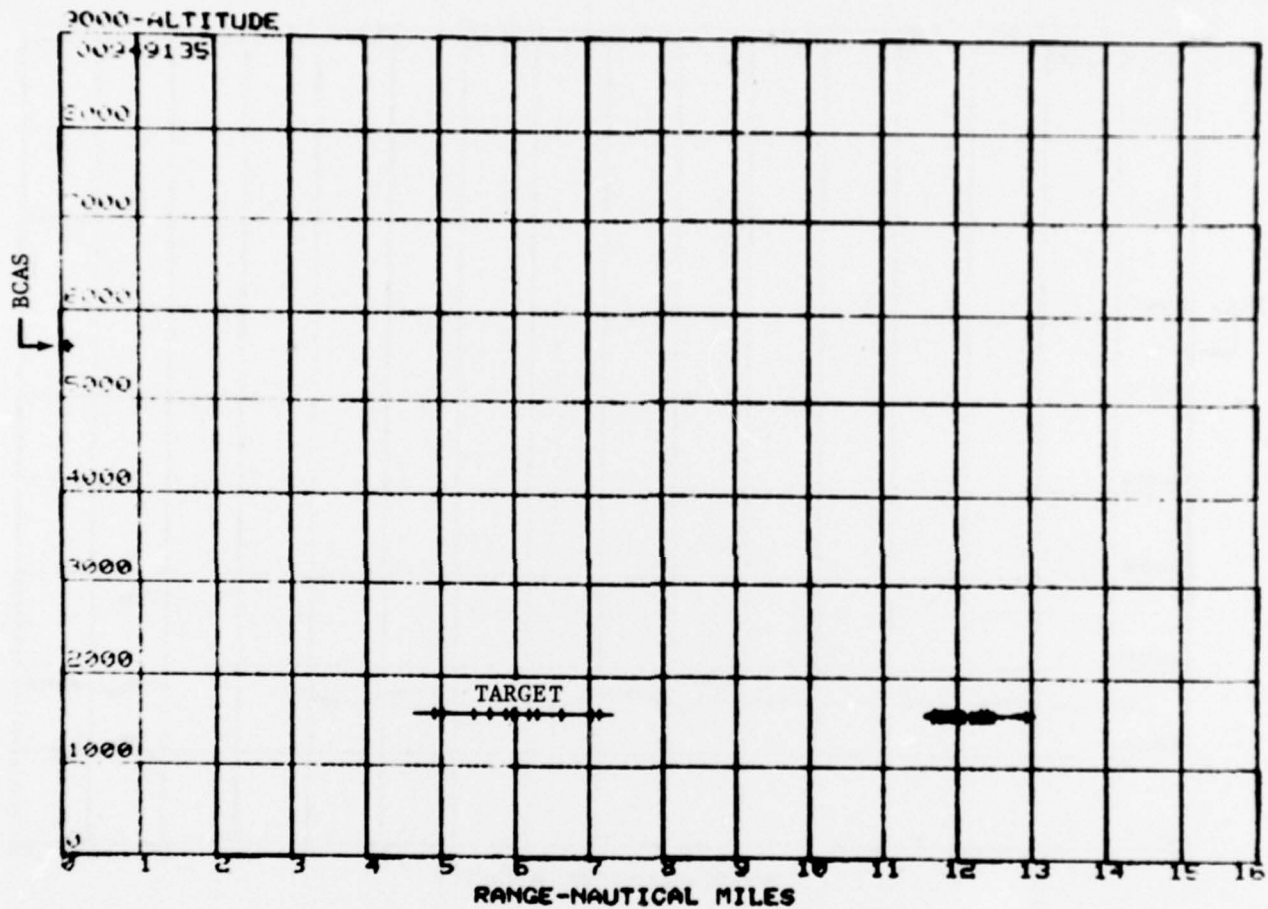


FIGURE B-8
OUTBOUND HEAD-ON ENCOUNTER (-4000 FT.)

BEST AVAILABLE COPY

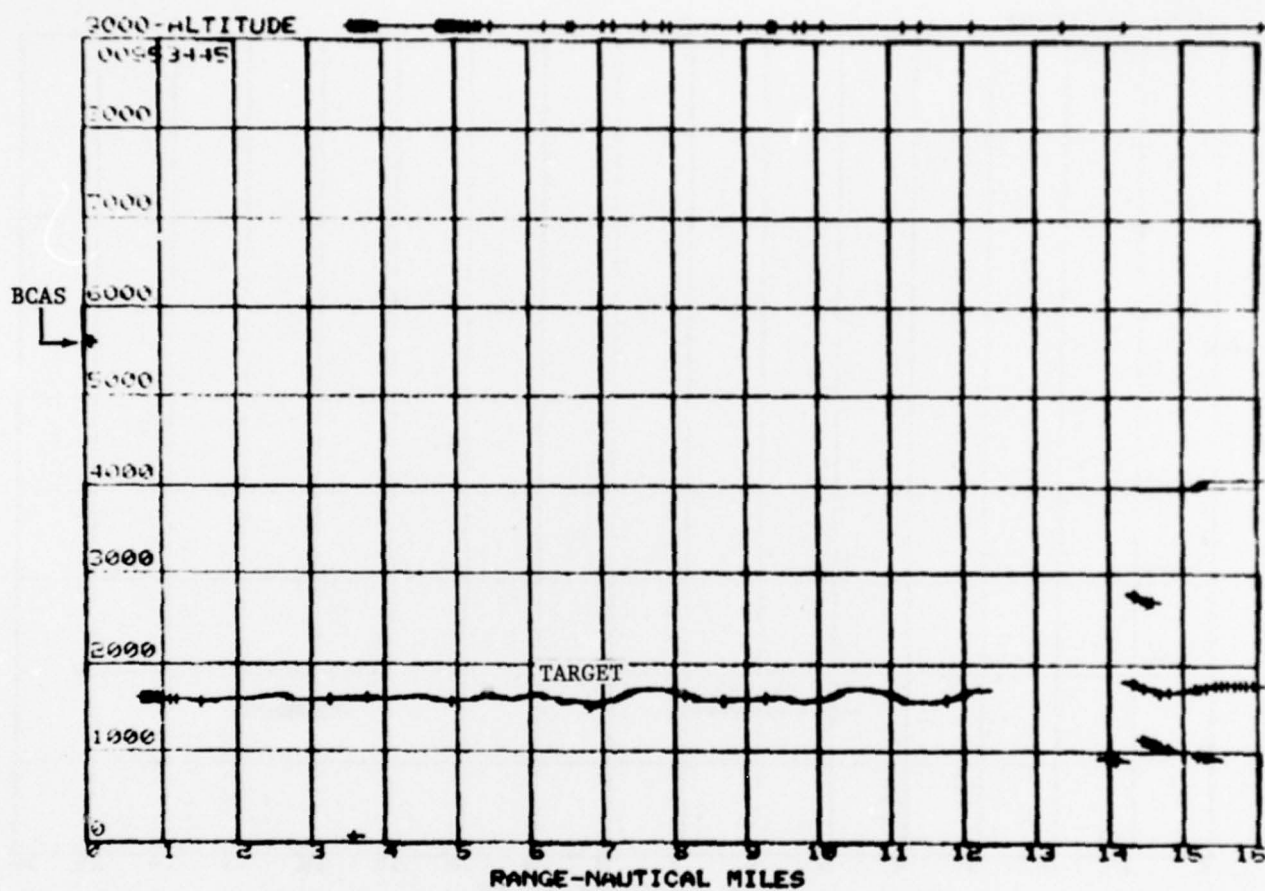


FIGURE B-9
INBOUND CROSSING ENCOUNTER (-4000 FT.)

BEST AVAILABLE COPY

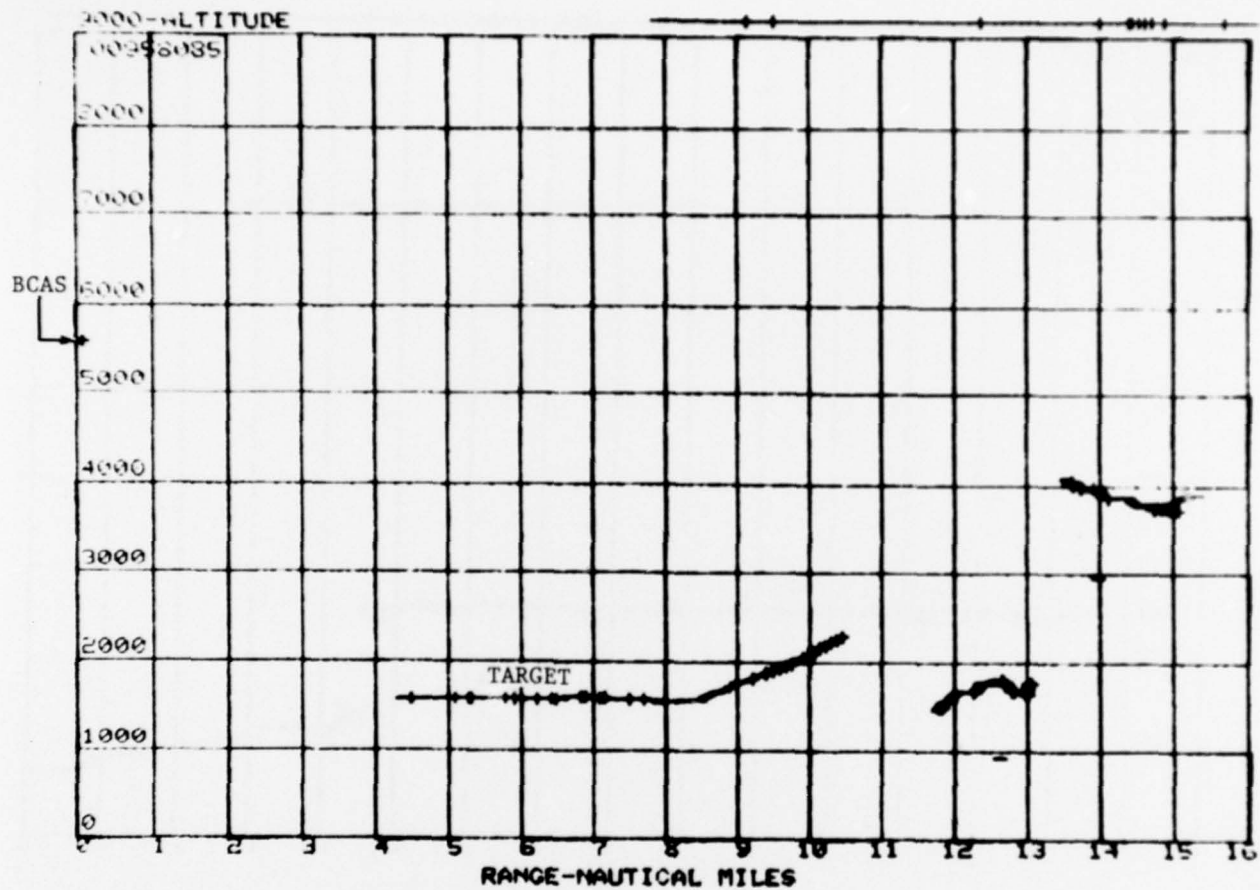


FIGURE B-10
OUTBOUND CROSSING ENCOUNTER (-4000 FT.)

BEST AVAILABLE COPY

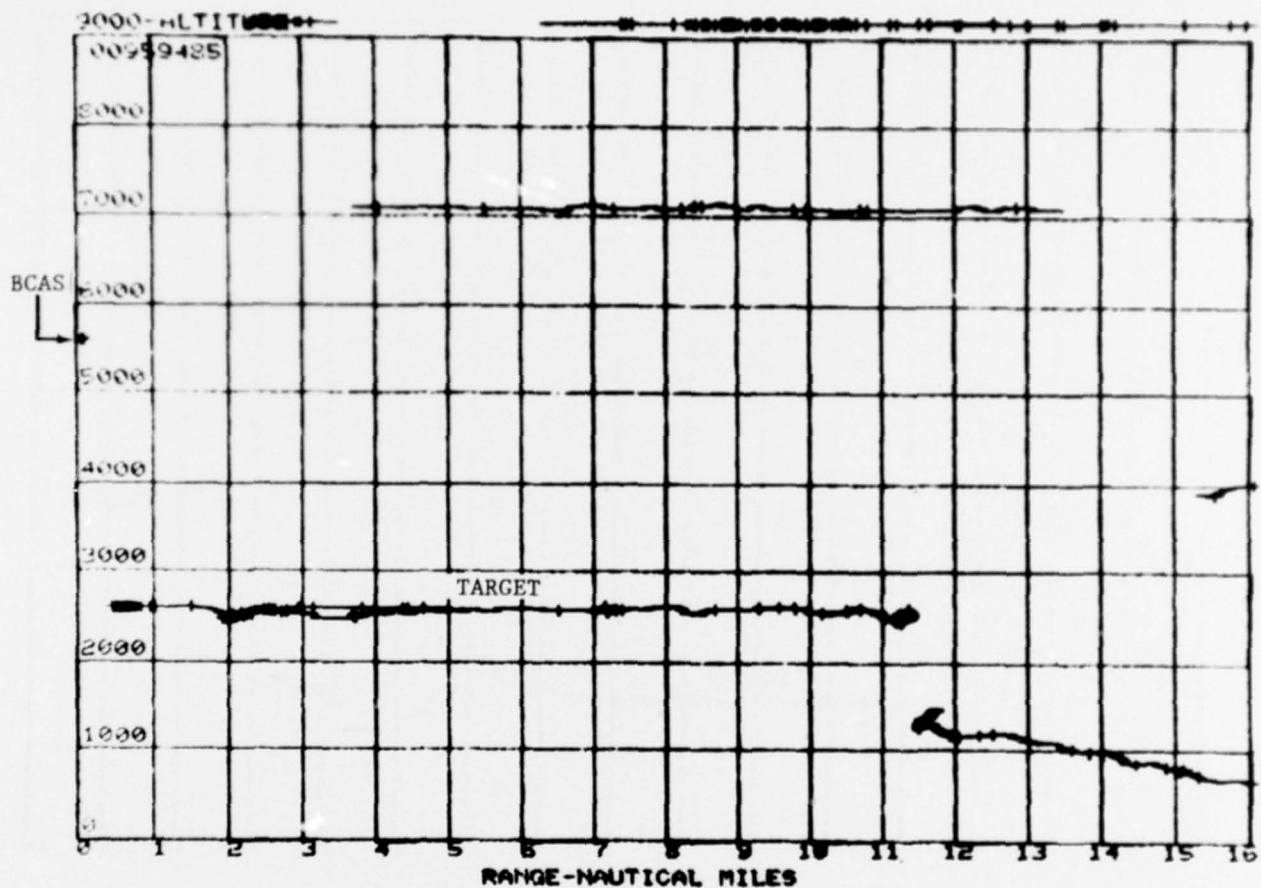


FIGURE B-11
INBOUND CROSSING ENCOUNTER (~3000 FT.)

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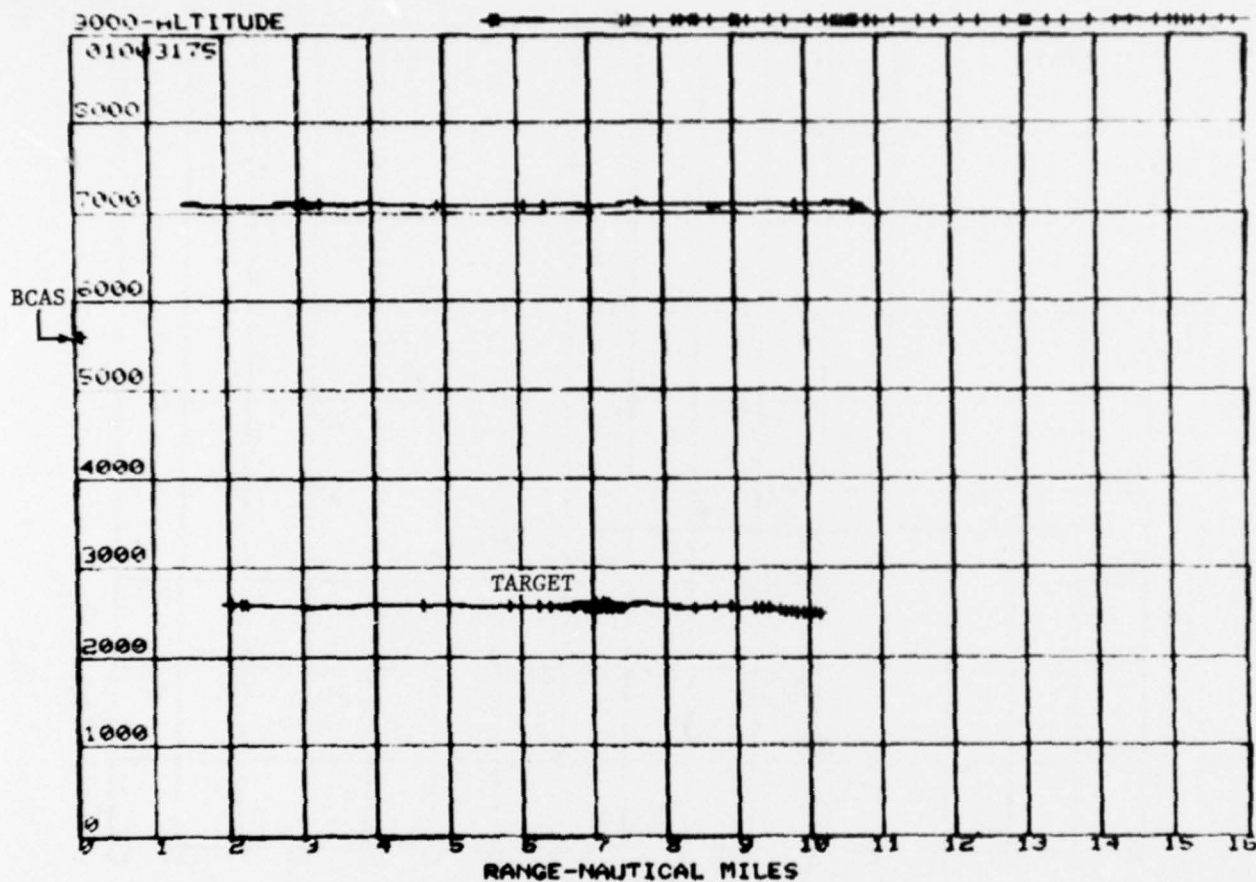


FIGURE B-12
OUTBOUND CROSSING ENCOUNTER (-3000 FT.)

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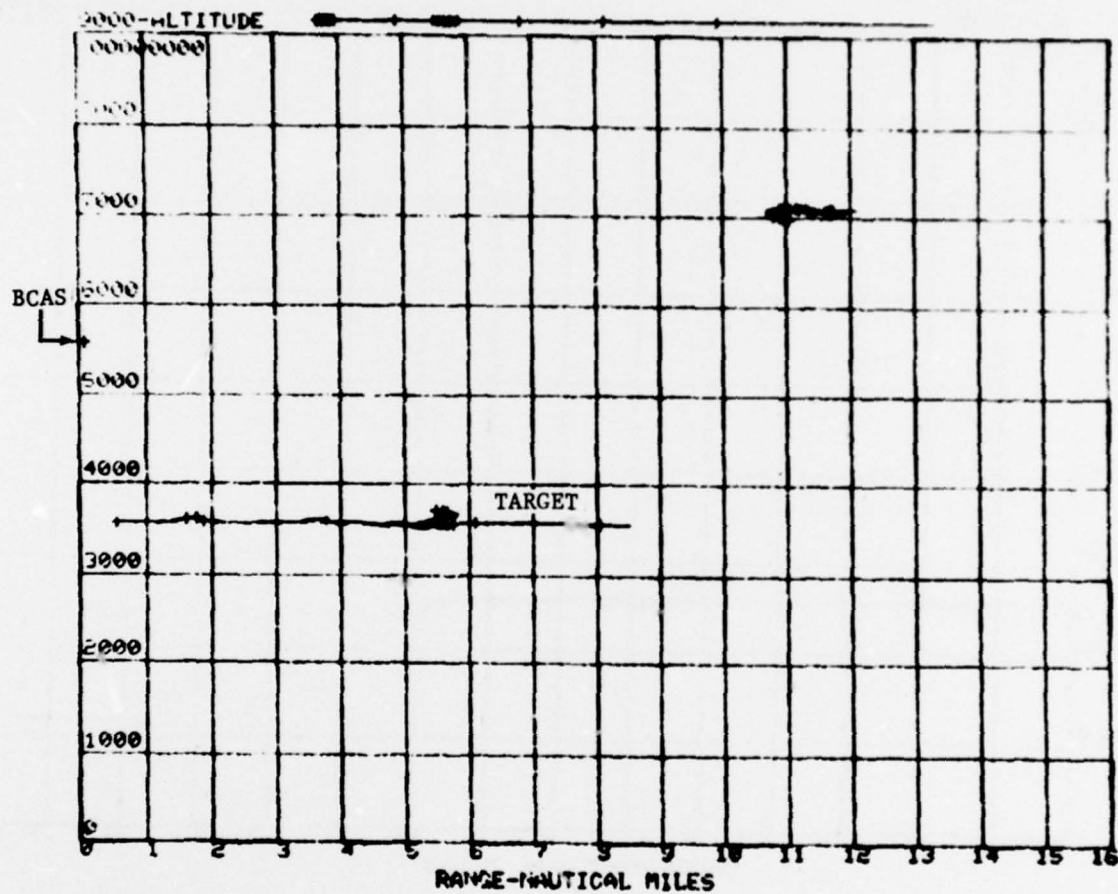


FIGURE B-13
INBOUND CROSSING ENCOUNTER (-2000 FT.)

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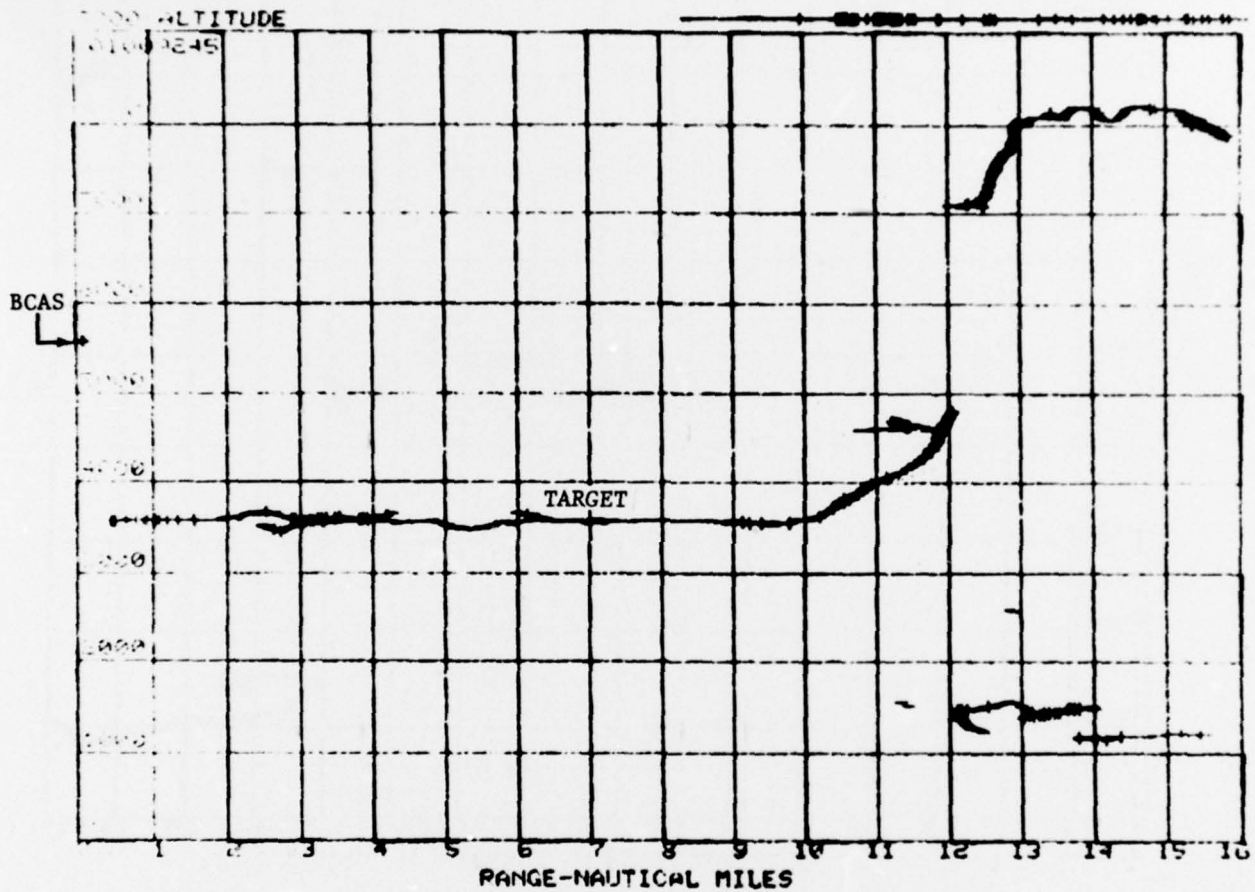


FIGURE B-14
OUTBOUND CROSSING ENCOUNTER (-2000 FT.)

BEST AVAILABLE COPY

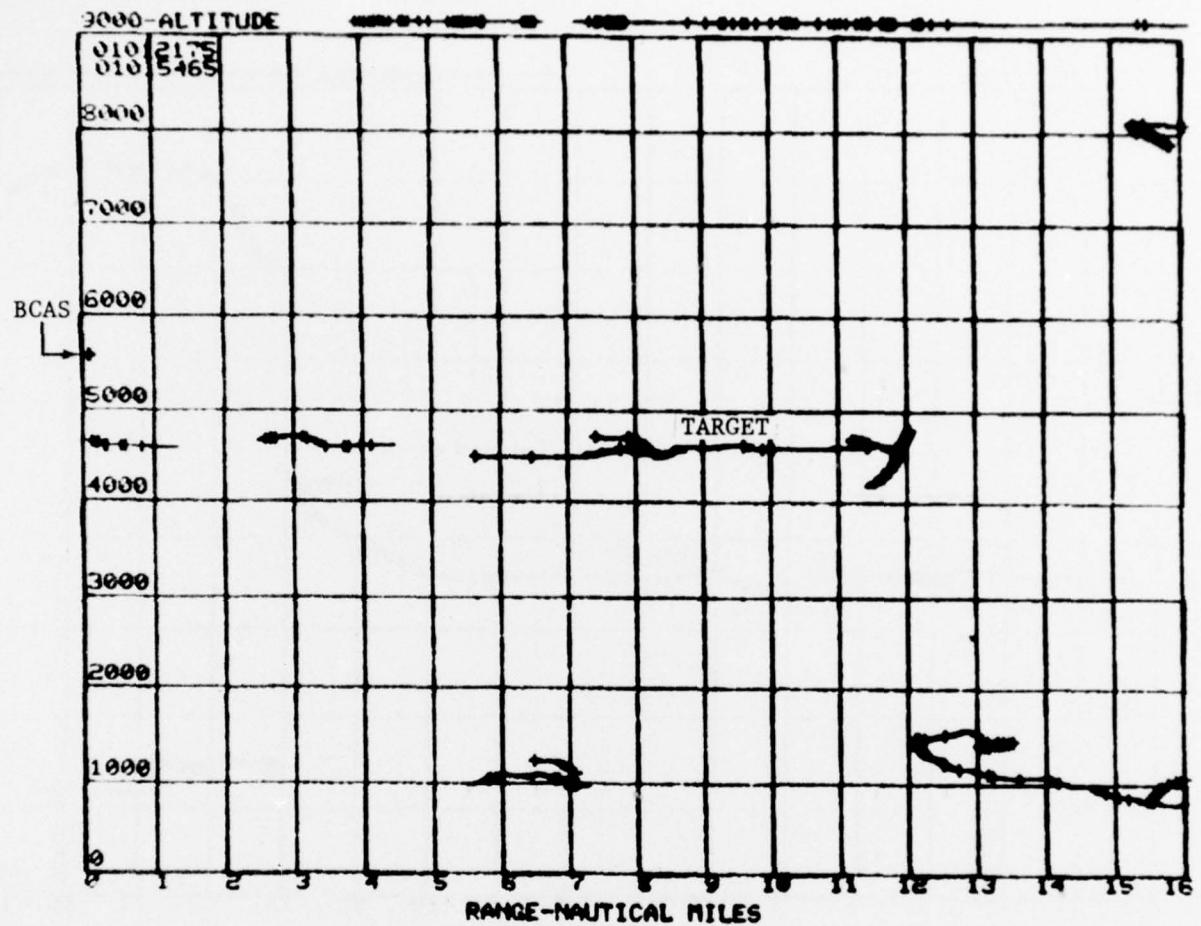


FIGURE B-15
INBOUND CROSSING ENCOUNTER (-1000 FT.)

BEST AVAILABLE COPY

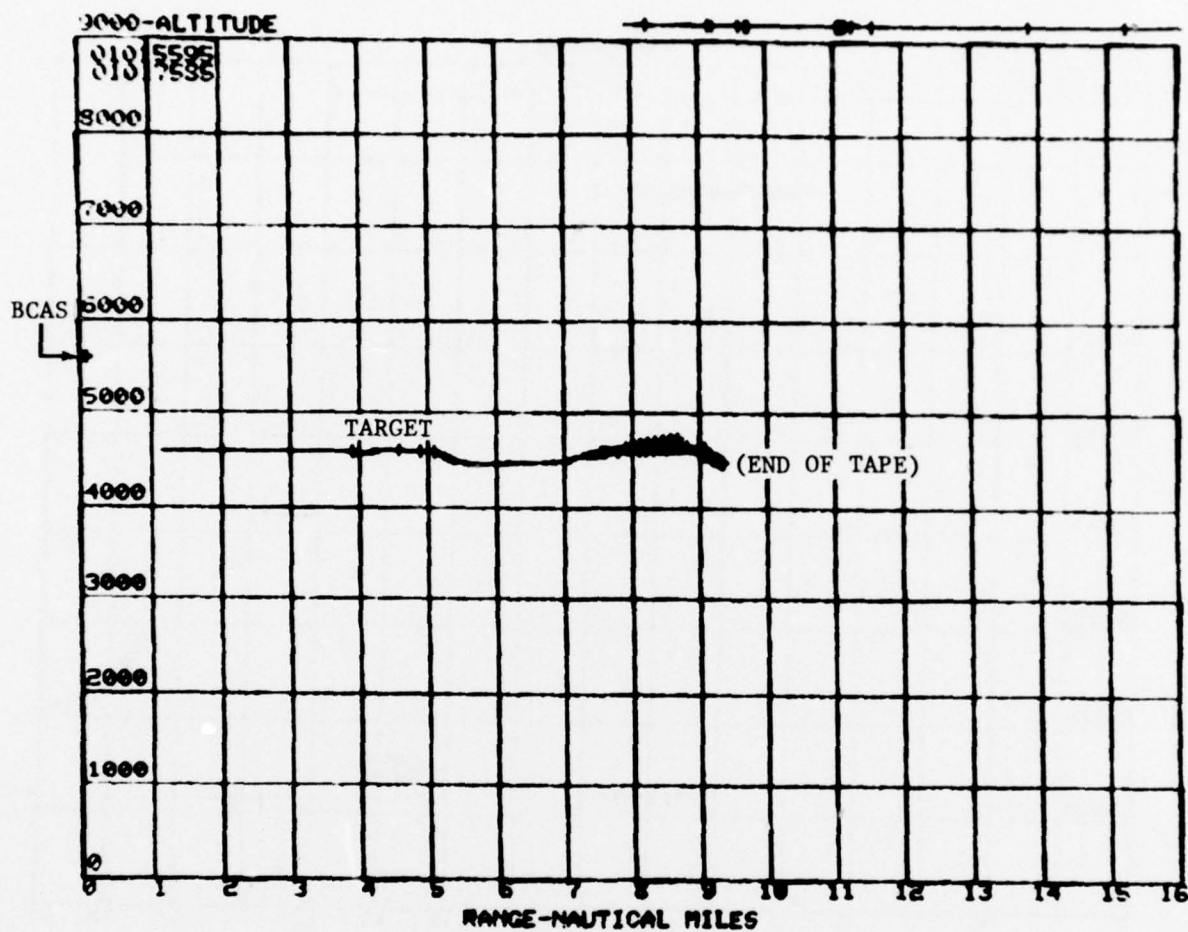


FIGURE B-16
OUTBOUND CROSSING ENCOUNTER (-1000 FT.)

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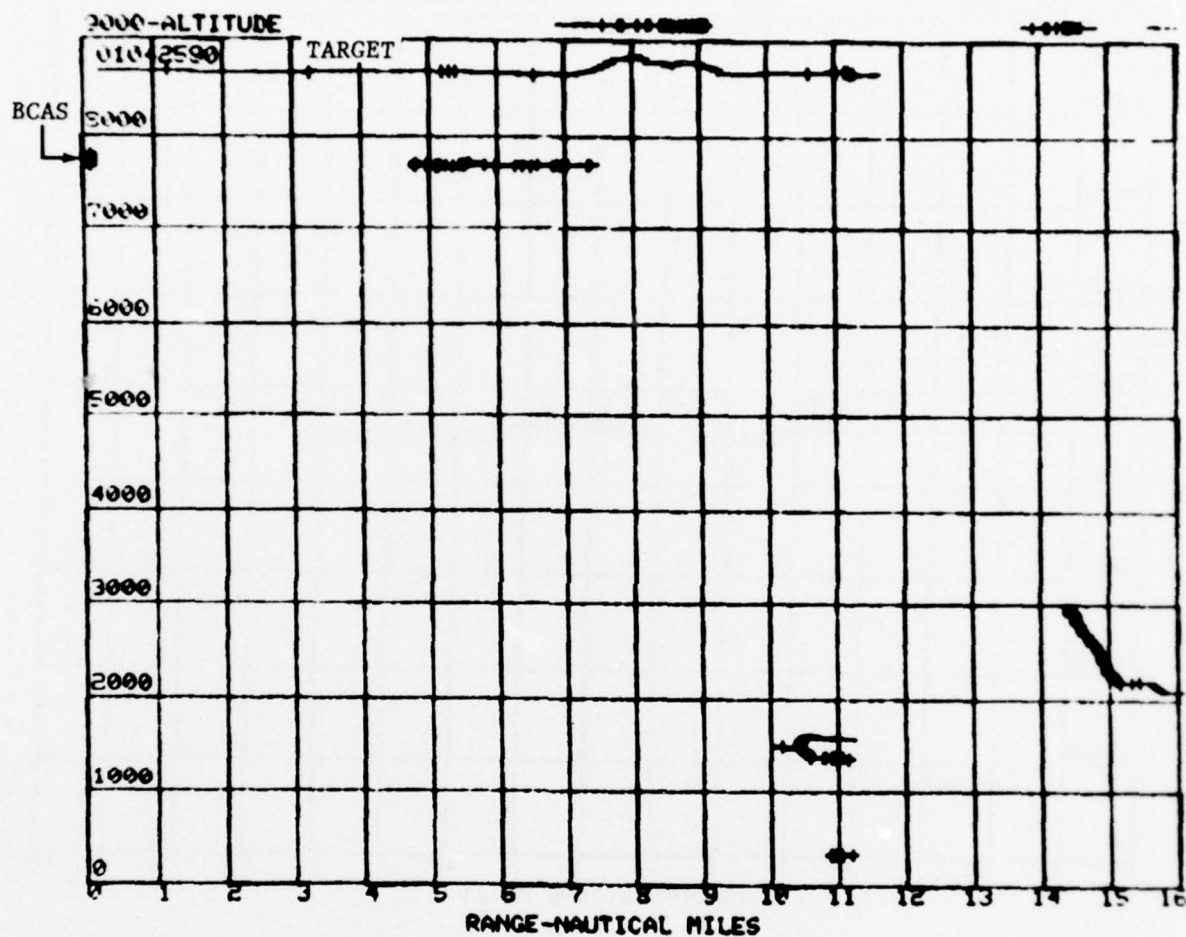


FIGURE B-17
INBOUND HEAD-ON ENCOUNTER (+1000 FT.)

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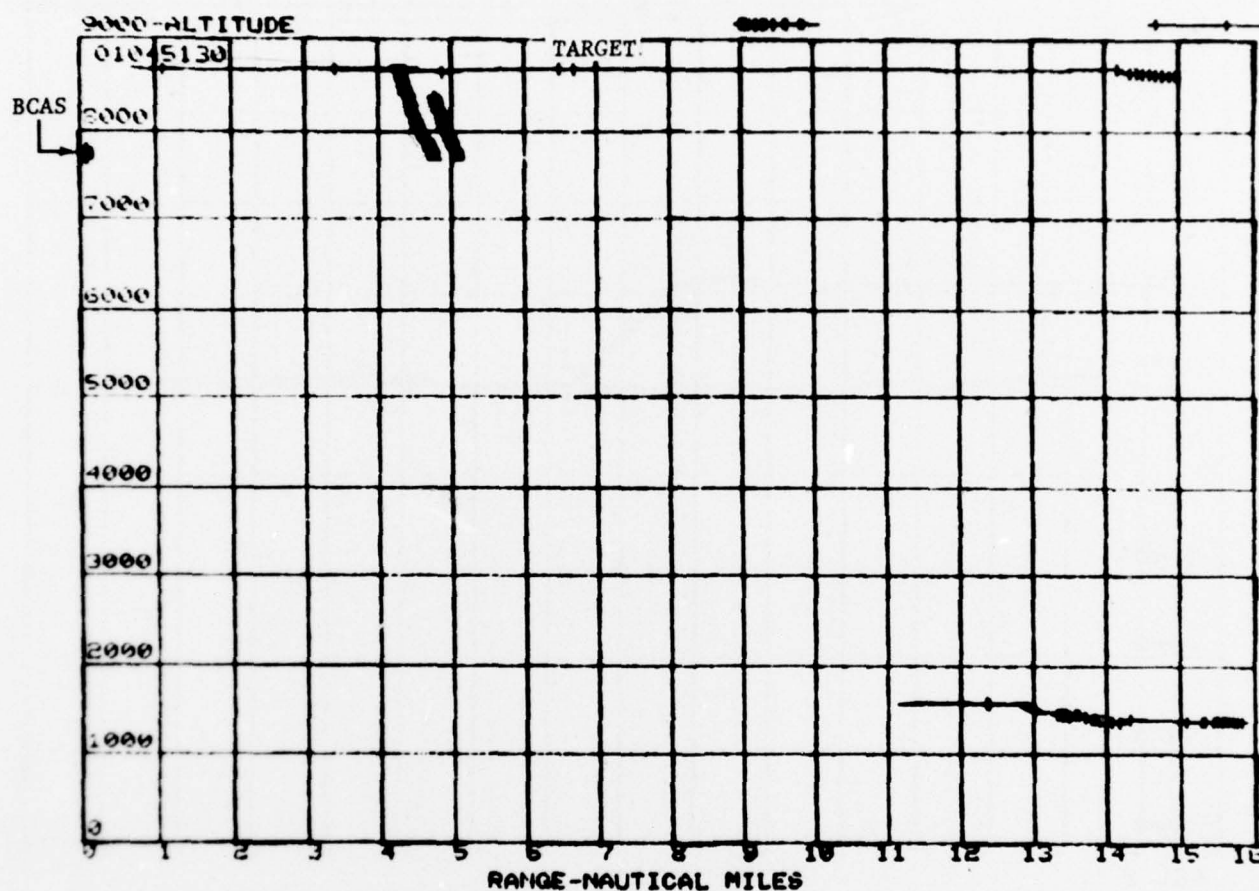


FIGURE B-18
OUTBOUND HEAD-ON ENCOUNTER (+1000 FT.)

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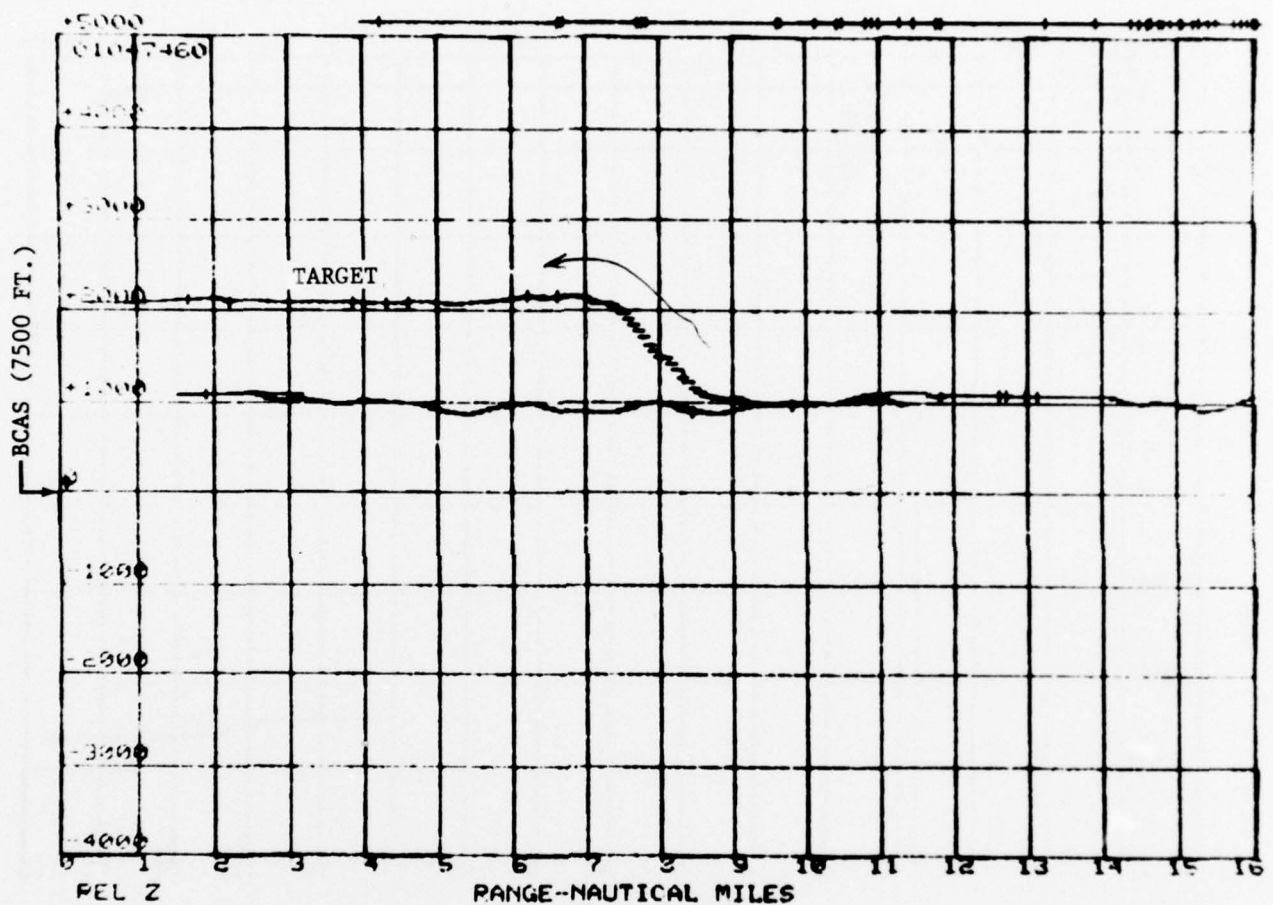


FIGURE B-19
INBOUND HEAD-ON ENCOUNTER (+2000 FT.)

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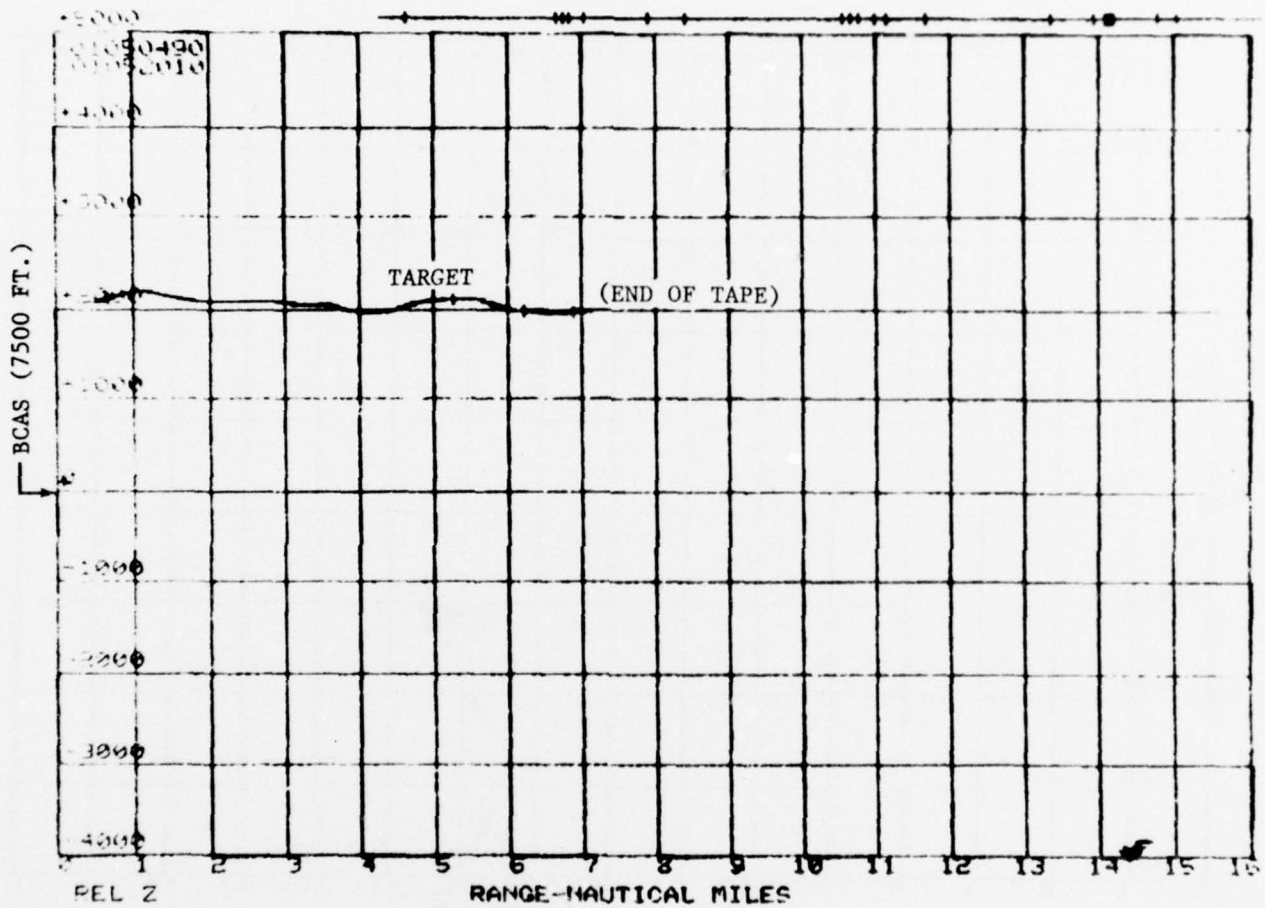


FIGURE B-20
OUTBOUND HEAD-ON ENCOUNTER (+2000 FT.)

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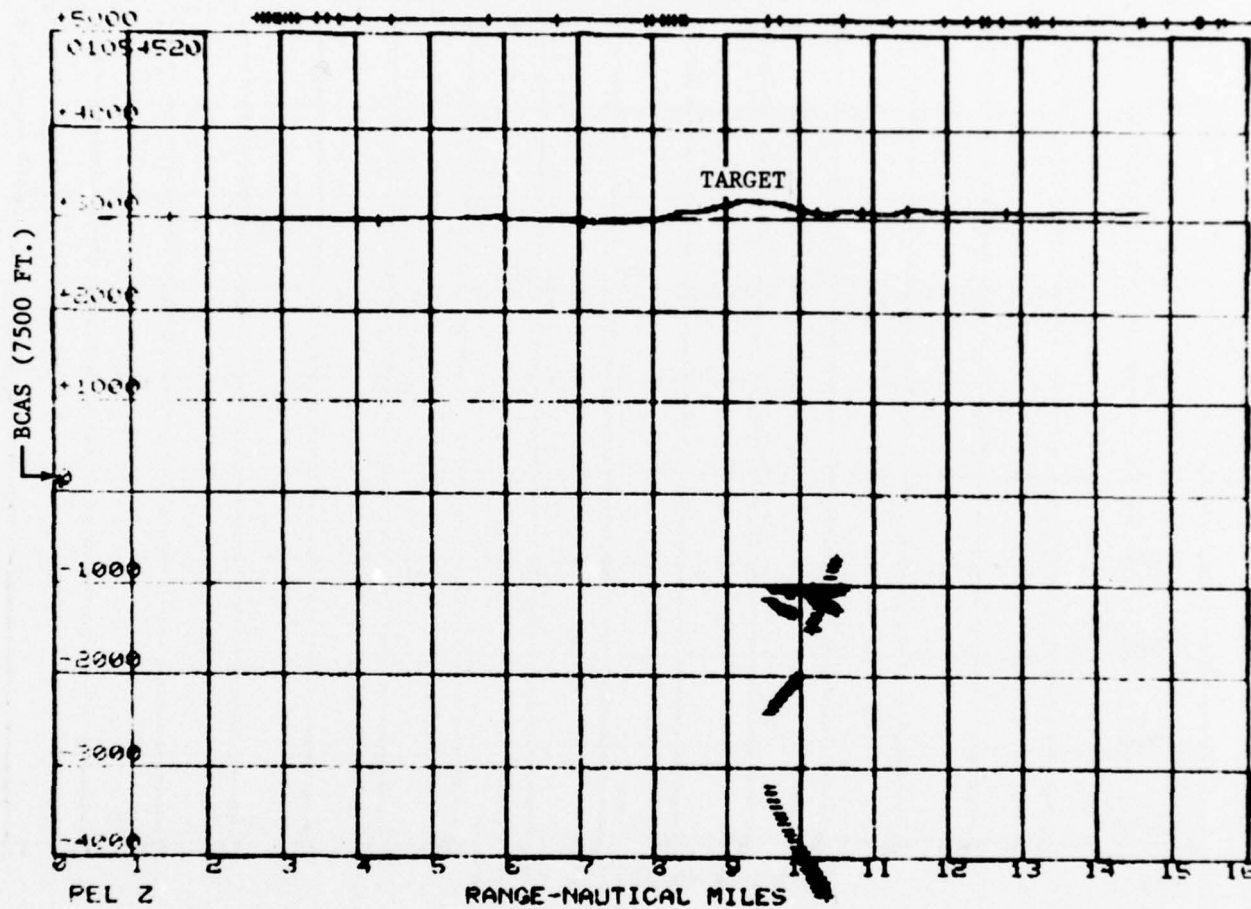


FIGURE B-21
INBOUND HEAD-ON ENCOUNTER (+3000 FT.)

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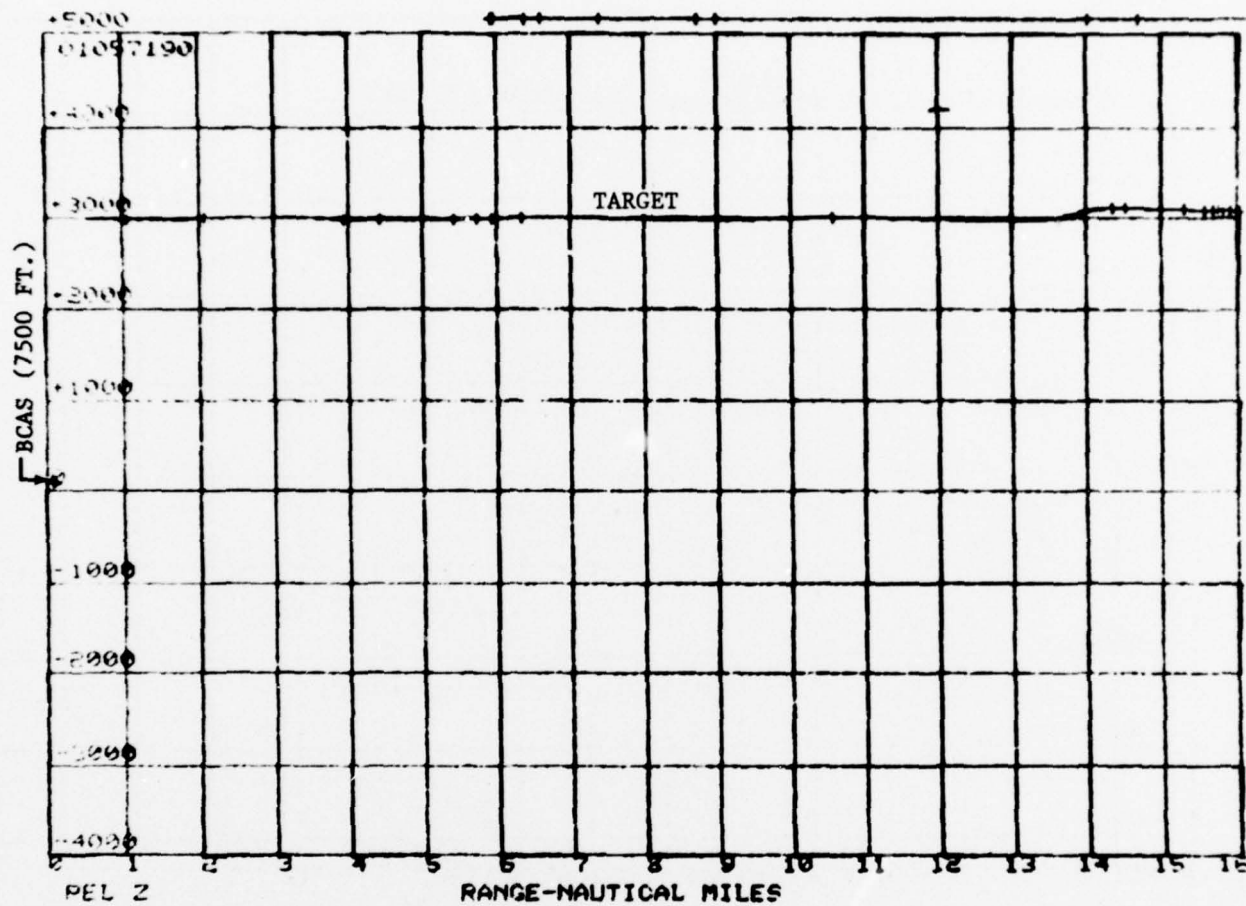


FIGURE B-22
OUTBOUND HEAD-ON ENCOUNTER (+3000 FT.)

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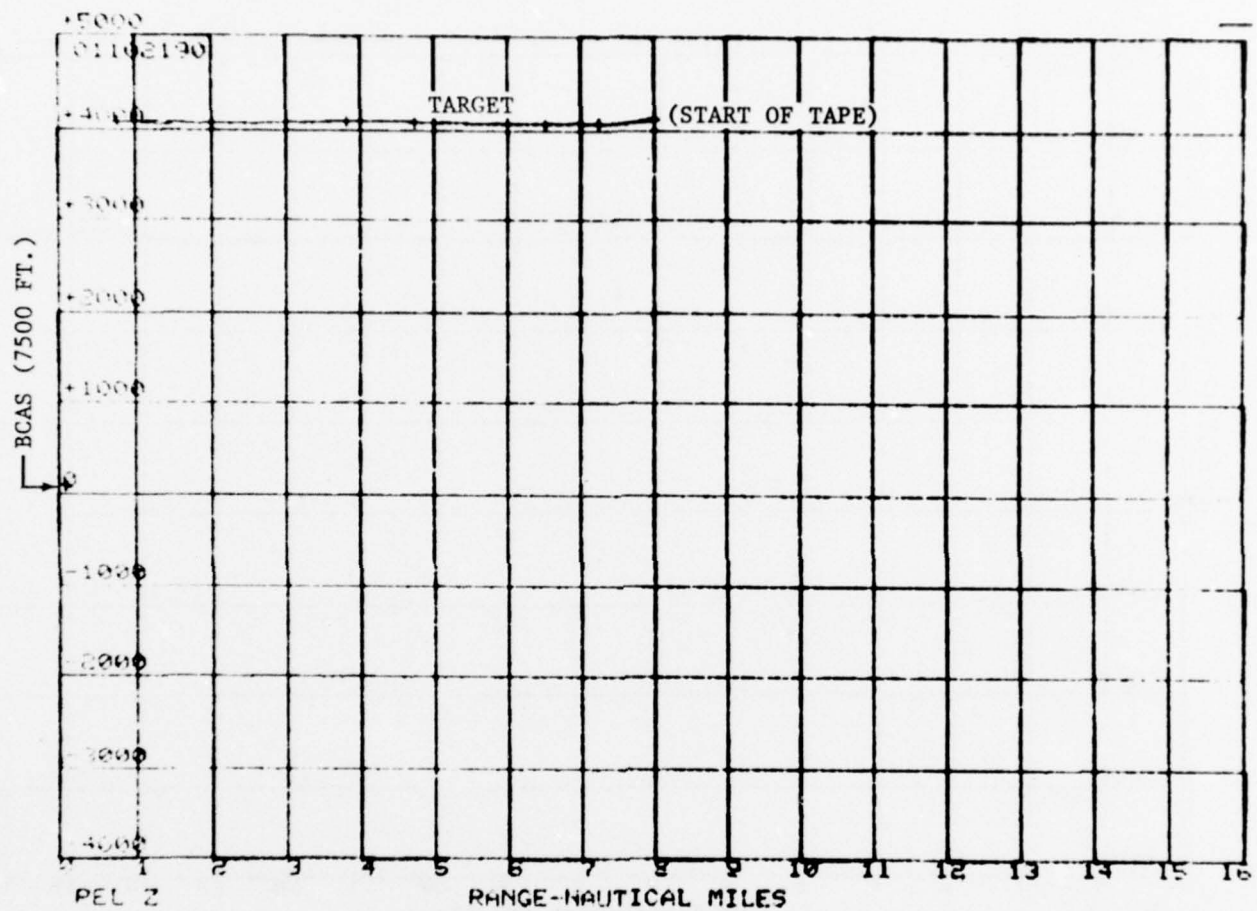


FIGURE B-23
INBOUND HEAD-ON ENCOUNTER (+4000 FT.)

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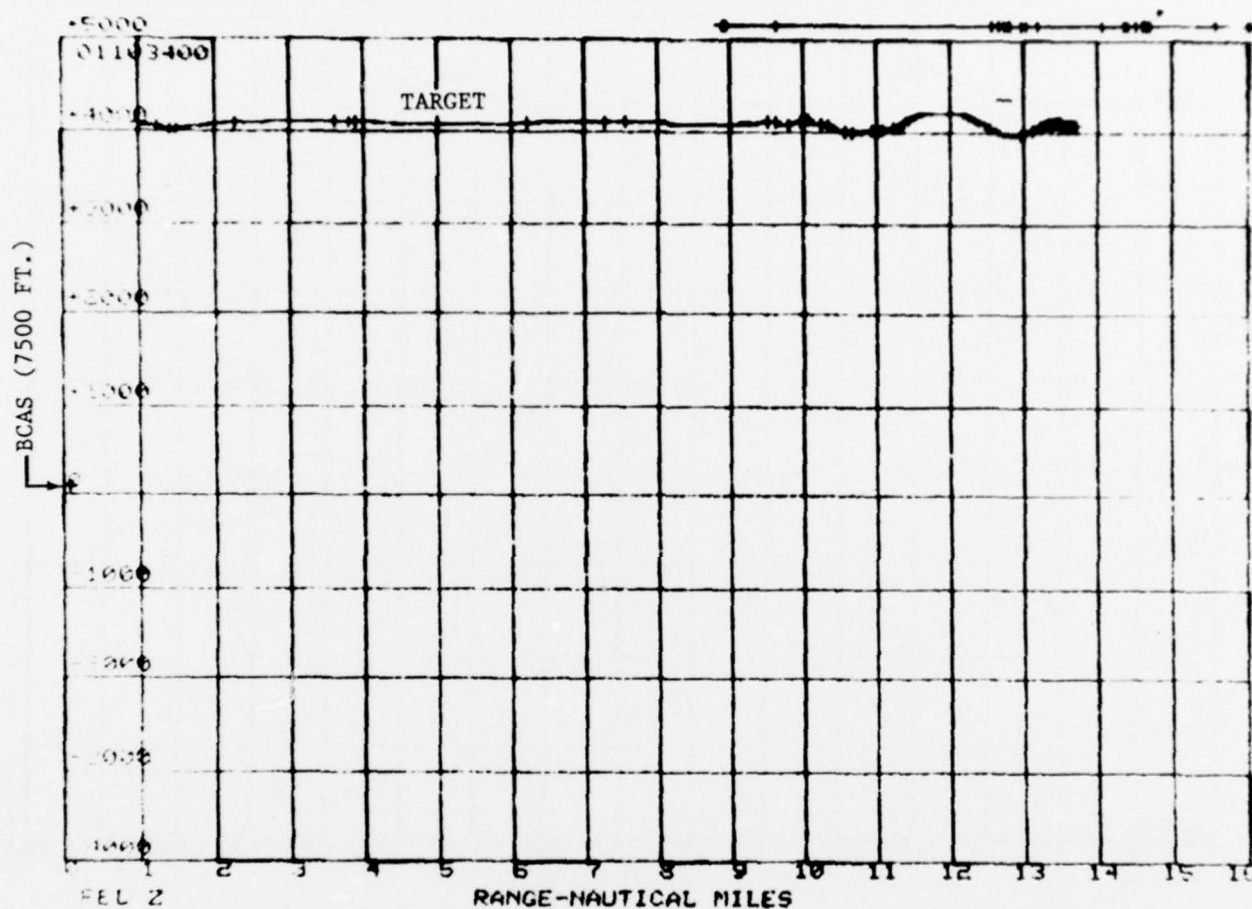


FIGURE B-24
OUTBOUND HEAD-ON ENCOUNTER (+4000 FT.)

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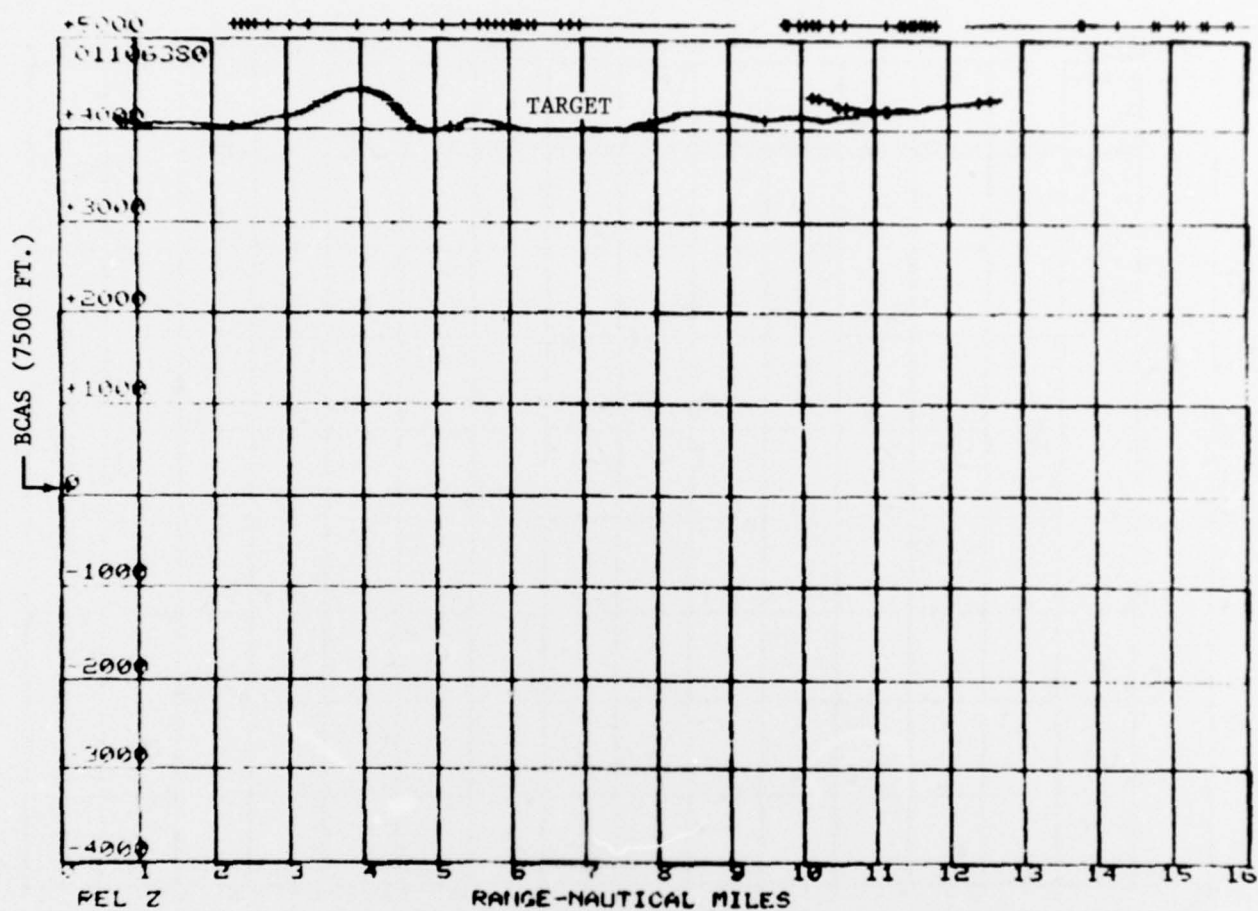


FIGURE B-25
INBOUND CROSSING ENCOUNTER (+4000 FT.)

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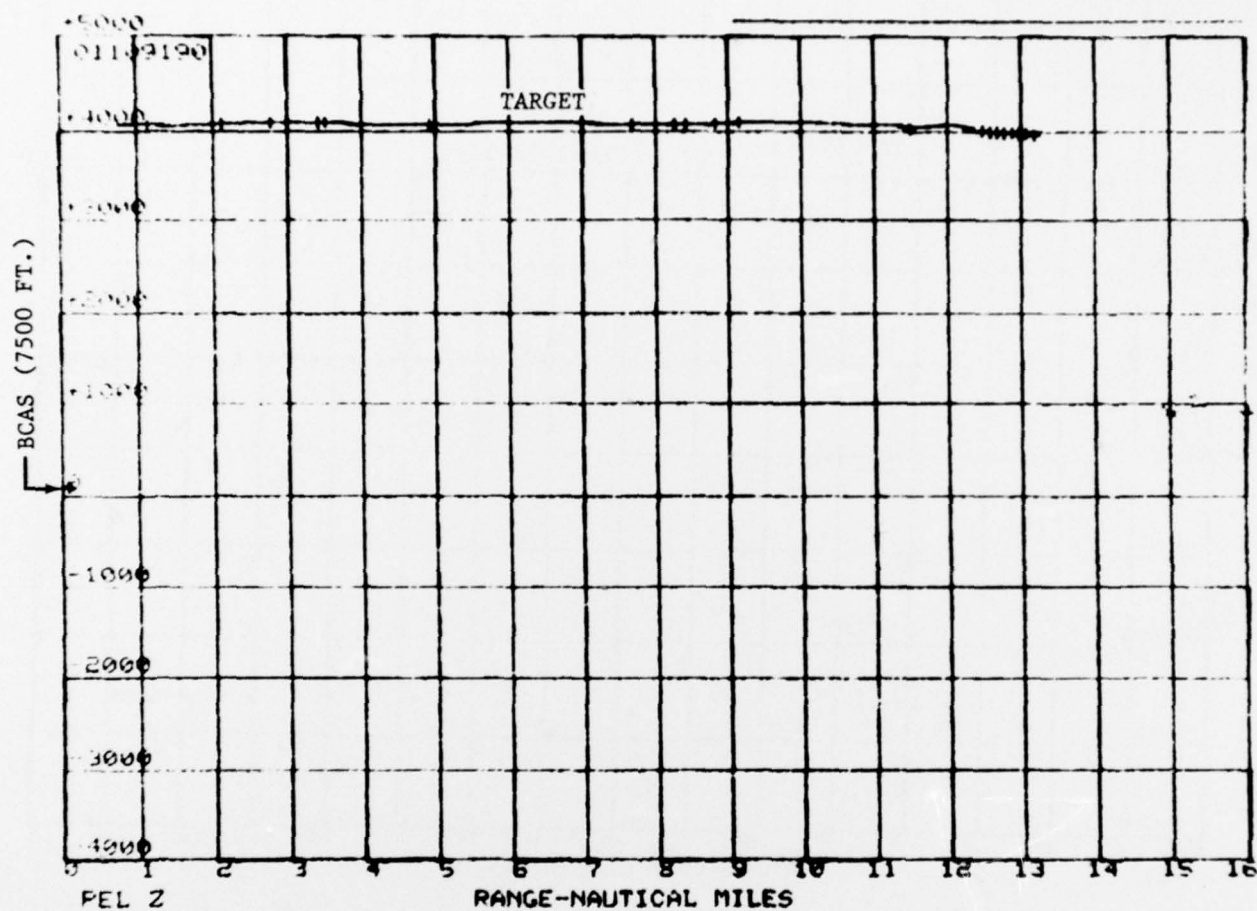


FIGURE B-26
OUTBOUND CROSSING ENCOUNTER (+4000 FT.)

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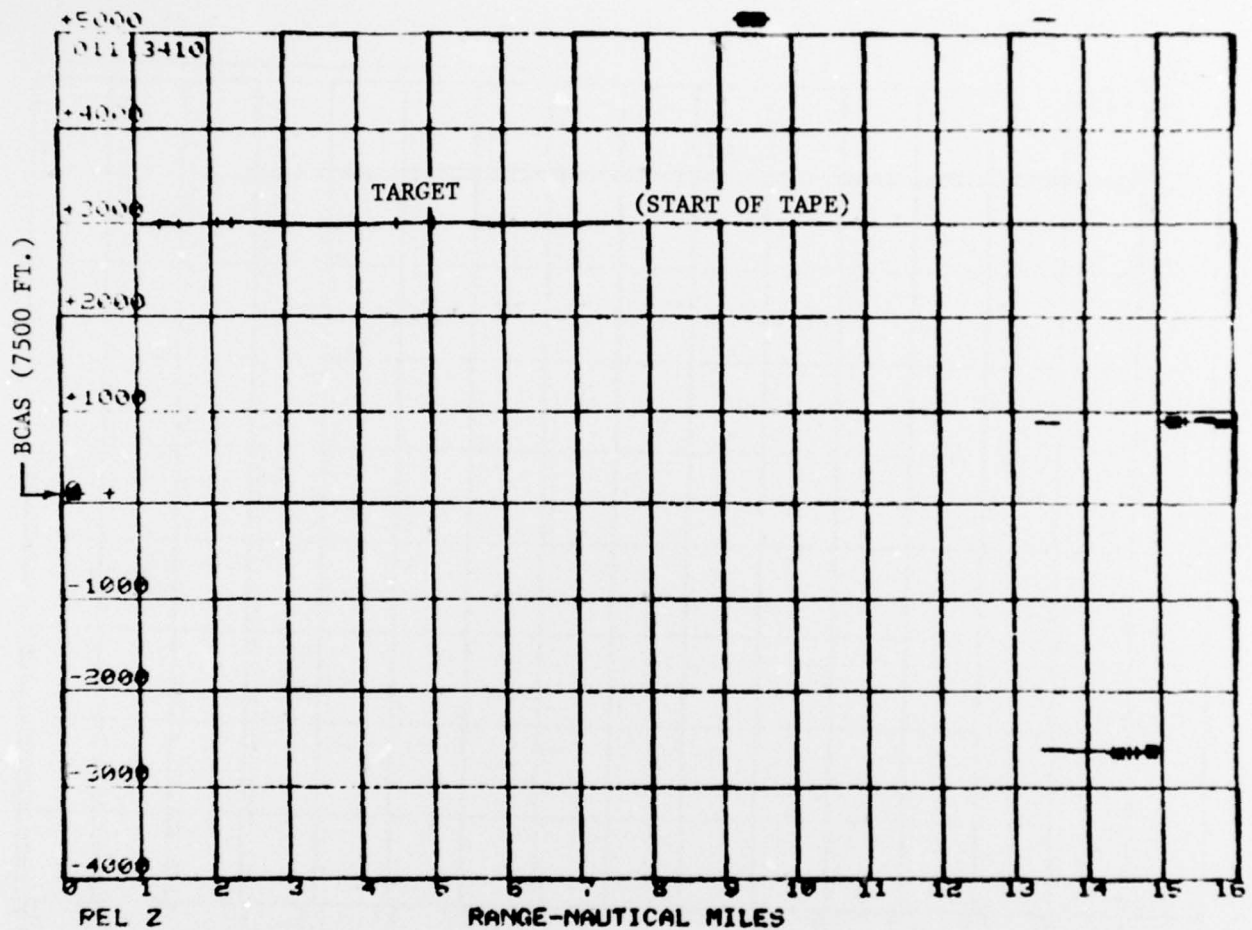


FIGURE B-27
INBOUND CROSSING ENCOUNTER (+3000 FT.)

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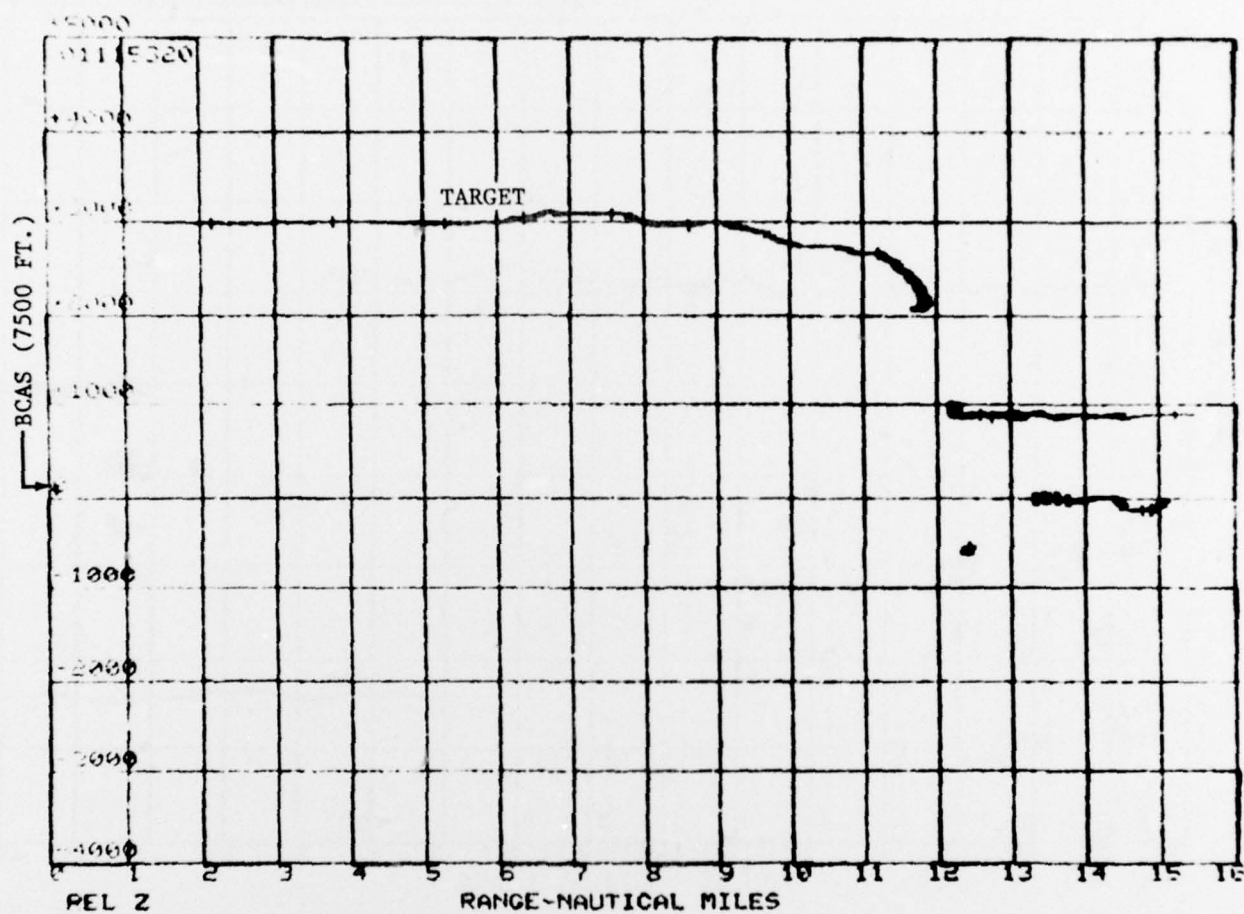


FIGURE B-28
OUTBOUND CROSSING ENCOUNTER (+3000 FT.)

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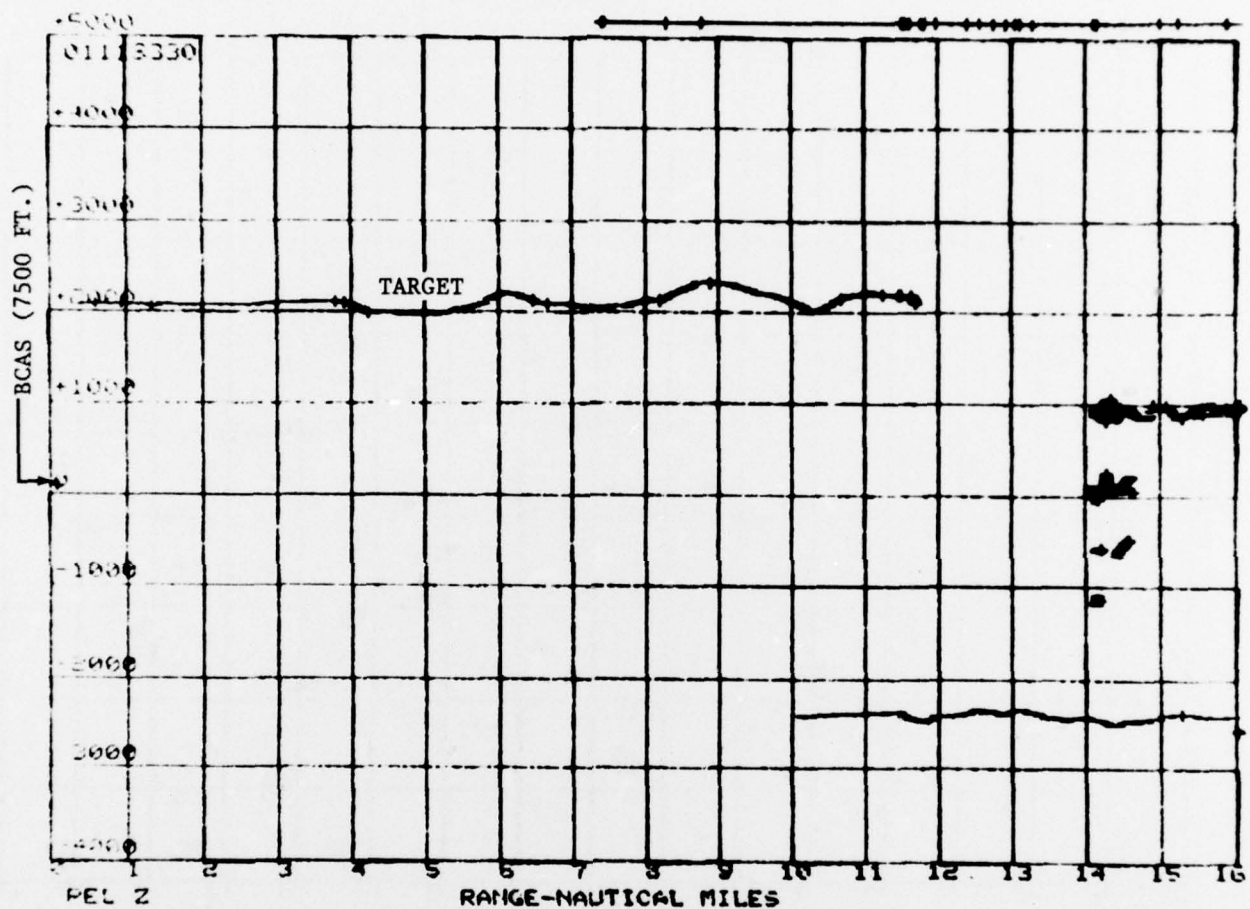


FIGURE B-29
INBOUND CROSSING ENCOUNTER (+2000 FT.)

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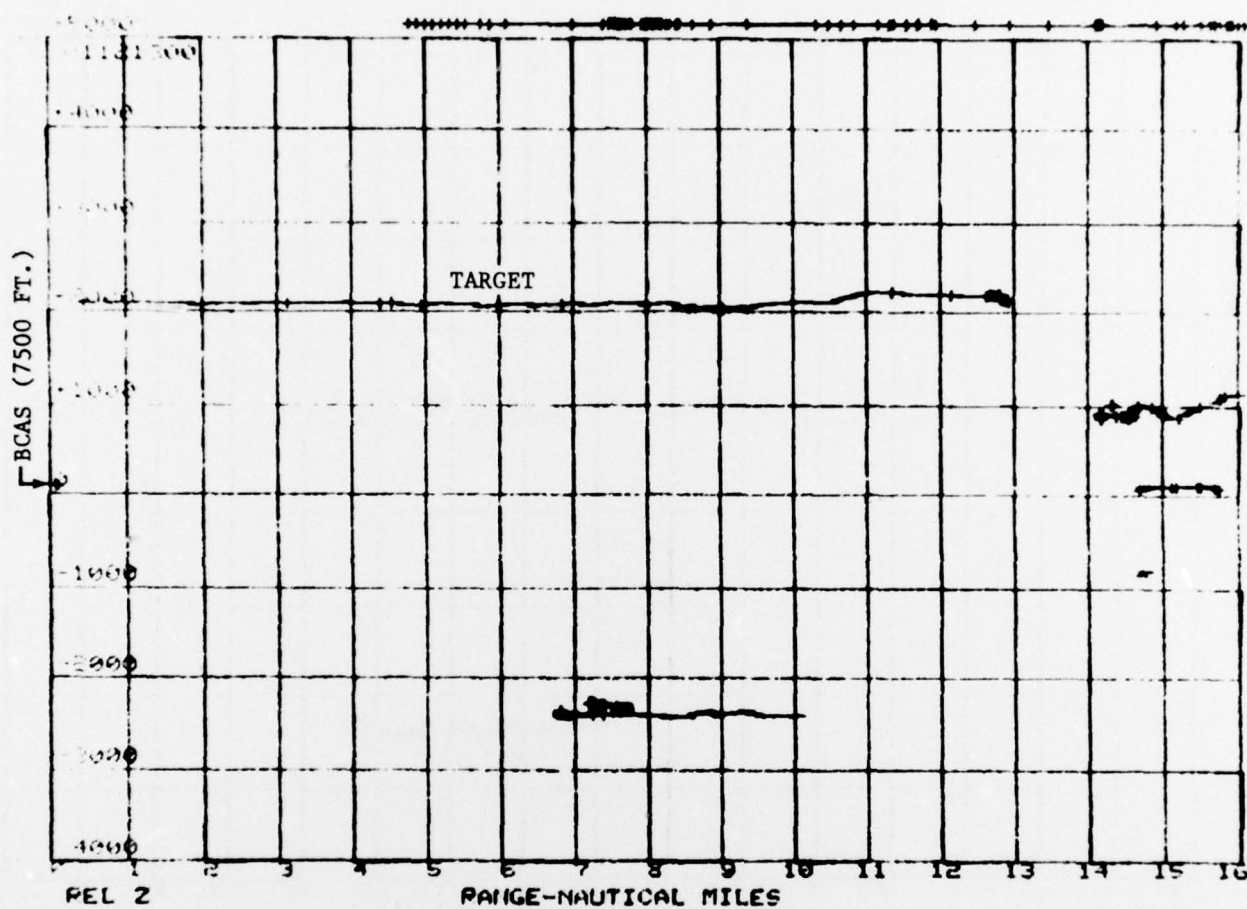


FIGURE B-30
OUTBOUND CROSSING ENCOUNTER (+2000 FT.)

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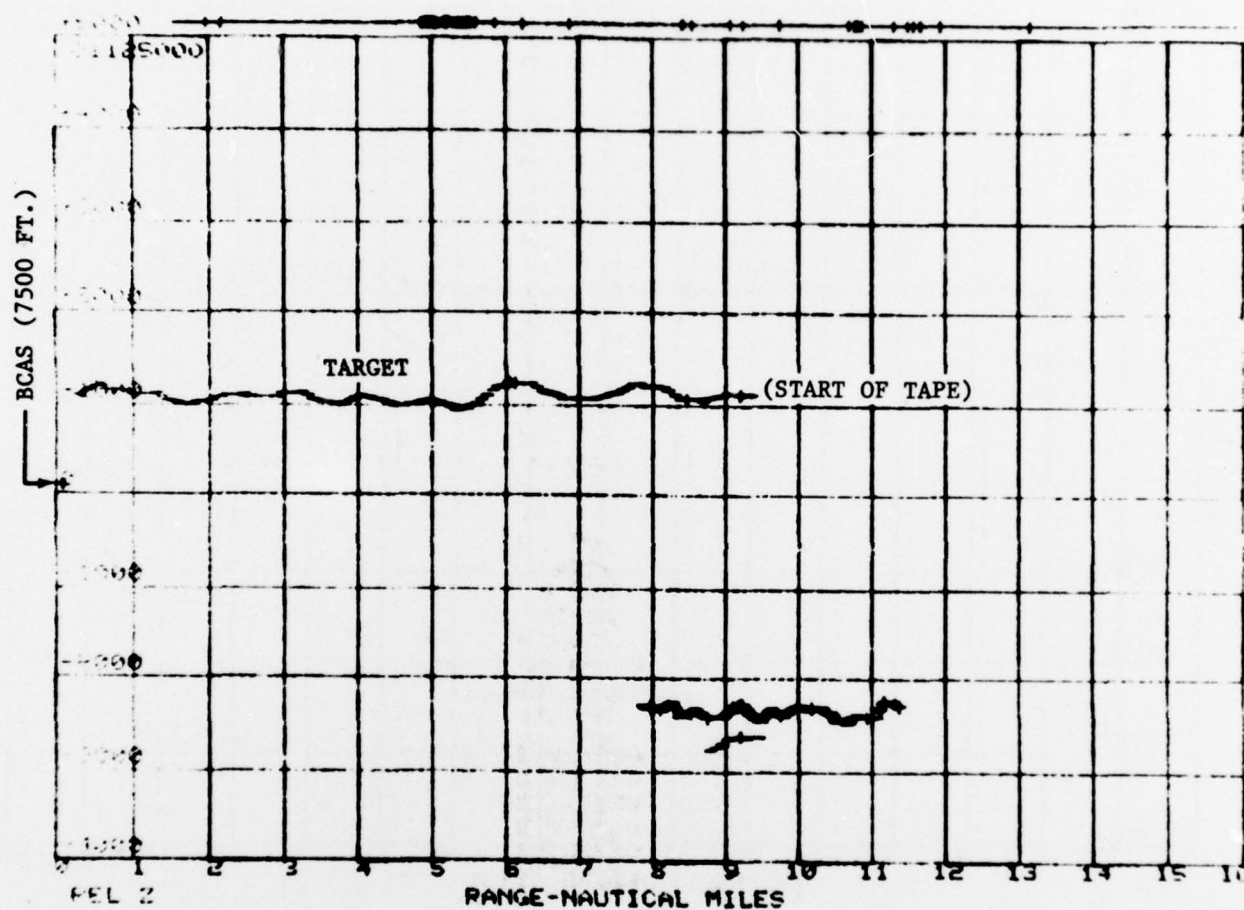


FIGURE B-31
INBOUND CROSSING ENCOUNTER (+1000 FT.)

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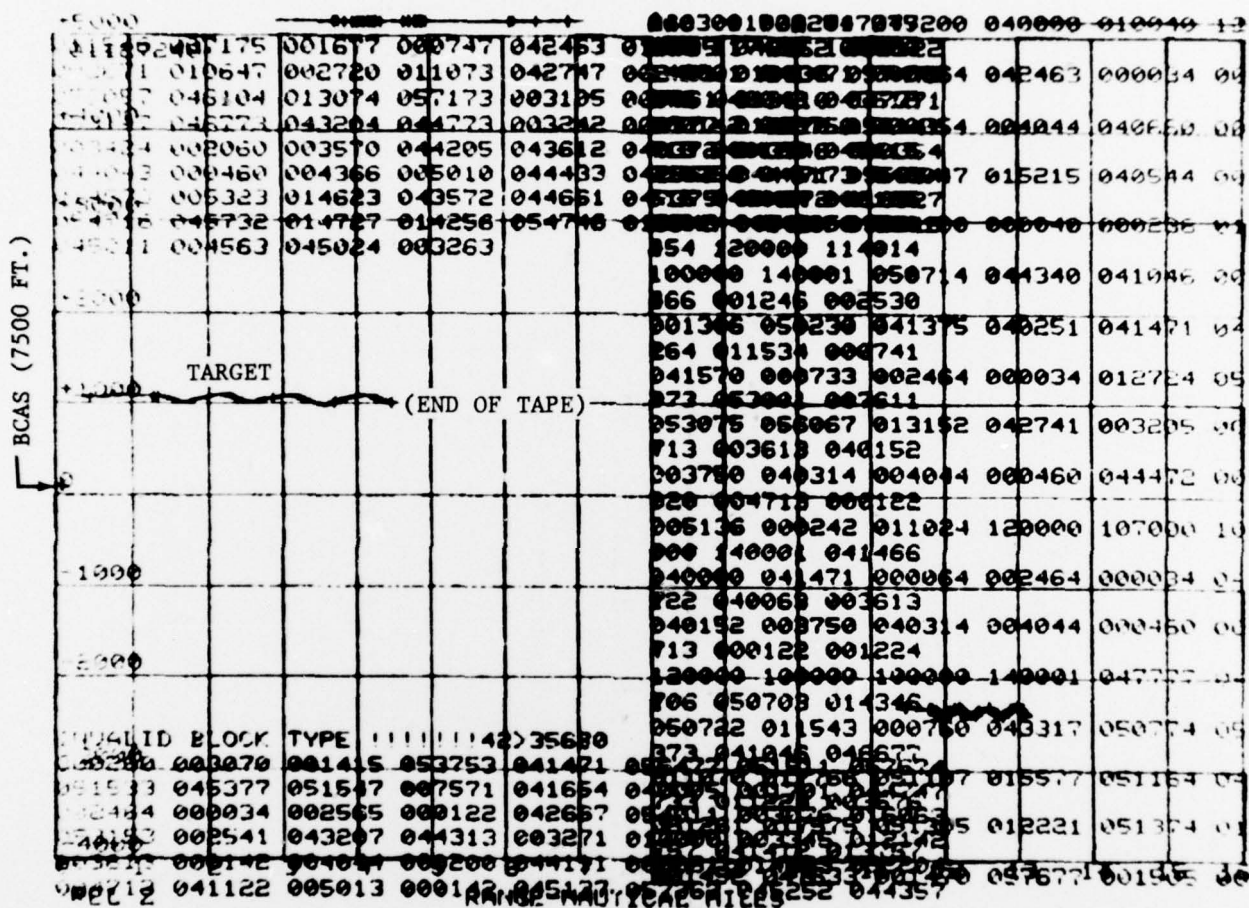


FIGURE B-32¹
OUTBOUND CROSSING ENCOUNTER (+1000 FT.)

APPENDIX C

POWER BUDGET

The link power budgets for nominal transponders are listed in Table C-1 for both the interrogation path (1030 MHz) and the reply path (1090 MHz). Nominal RF cable losses of 3 dB are assumed at each end, and a unity-gain antenna is also assumed. The large interrogator power of 2 kW, which was available in the test bed, was used in order to ensure that at least the interrogation link was sound. For ultimate use, the power would be substantially less than that, to equalize the link margins.

Table C-1 is computed for no antenna shielding and for a range of 10 nmi. As these factors change, and as the actual values for transponder power and sensitivity are used, the margins change accordingly.

TABLE C-1
POWER BUDGET

	1030 MHz	1090 MHz
Transmitter power	33 dBW (2 kW)	23 dBW (200 kW)
Antenna gain	0 dB	0 dB
Path loss	-118 dB (10 nmi)	-118 dB (10 nmi)
Cable losses	-6 dB	-6 dB
Received power	-91 dBW	-101 dBW
Minimum triggering level	-101 dBW (-71 dBm)	-106 dBW (-76 dBm)
Margin at 10 nmi	10 dB	5 dB

APPENDIX D

DABS INTEGRATION

The subject of this report has been the performance of the active ATCRBS mode of BCAS. This airborne test bed at NAFEC is now being upgraded to include the active DABS mode. This capability will provide both for the surveillance of other BCAS aircraft (as well as any DABS aircraft) when out of coverage of the ground surveillance system, and enable air-to-air data link to provide for coordinated maneuvers when needed.

Recognizing the limitation that synchronous garble places on the ATCRBS mode, the DABS mode is designed to be free of any type of interrogation that could produce synchronous garble. For this reason DABS surveillance is based upon the discrete address interrogation. This eliminates synchronous garble for the BCAS in the same way as for the DABS ground sensor. In order to be discretely addressed, however, an aircraft's DABS address must be known. To enable their acquisition by the BCAS system, the DABS transponders will emit a parity-protected squitter transmission periodically at about a one-Hz rate. Encoded within the squitter transmission is the DABS address, and a truncated pressure altitude code (LSB = 1000 feet). The availability of squitter replies permits the DABS mode to operate with a minimal number of interrogations thereby minimizing ground system interference. This is done by making use of the altitude information contained within the passively received squitter replies so that active interrogations are required only when a target is approximately co-altitude.

When a BCAS-equipped aircraft receives a squitter, it checks the (truncated) altitude of the target against its own altitude to determine whether the target should be ignored, immediately acquired in range, or tracked in altitude to determine if the altitude difference is decreasing at a fast enough rate to warrant range acquisition. When squitter processing determines that a target should be acquired, the target ID is placed in an acquisition queue. Four times per second, as a normal part of the DABS surveillance process, the acquisition queue is examined to determine if one or more new squitters have been received. If so, up to four discrete acquisition interrogations are transmitted per second to determine the range of the target. After two or more acquisition replies have satisfactorily correlated, the range and speed capability of the target are tested to determine if it is in the range threat zone. If so, the target is added to the active track file. If the target is not within the range zone, a calculation is made of the minimum time required for it to penetrate this zone, and it is placed in a dormant file until that time has elapsed. While dormant, subsequent acquisition attempts are inhibited. When the range falls within the programmed limit, the aircraft is then regularly interrogated at 1 second intervals to establish and maintain a high accuracy track.

Integration of the ATCRBS and DABS modes will be accomplished with the Real Time Operating System that is a standard software package of the NOVA computers. The test bed actually uses the ruggedized version of the computer as built by the Rolm Corporation. Figure D-1 shows the main software configuration that will be used; the ATCRBS surveillance program is the one used to obtain the results reported here.

ROLM 1602 MINICOMPUTER, 32K MEMORY

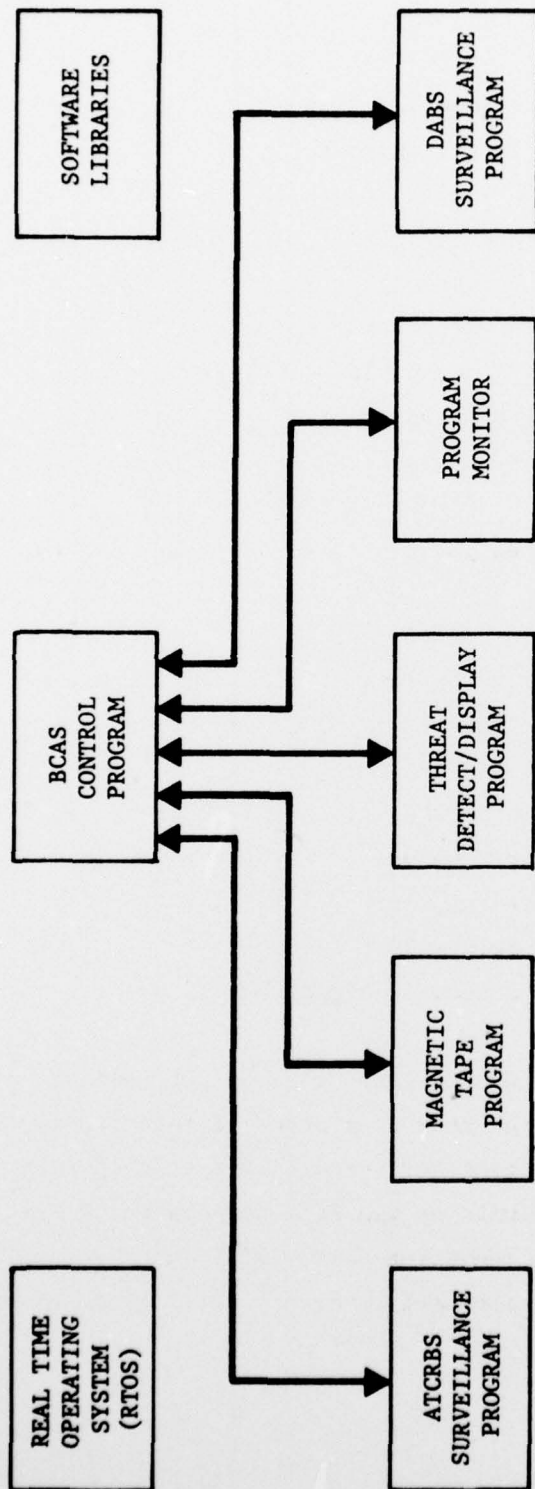


FIGURE D-1
SOFTWARE CONFIGURATION OF UPGRADED ACTIVE MODE TEST BED

APPENDIX E

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